CHE 1031: General Chemistry I

1. Essential ideas

1. Essential ideas

1.1 Chemistry in context

- *Outline historical development of chemistry*
- *Provide examples of chemistry in everyday life*
- Describe the scientific method
- Differentiate between hypotheses, theories & laws
- Provide examples of macroscopic, microscopic & symbolic domains

Chemistry

Chemistry *(n): the study of matter & the* ***changes*** *it undergoes*

- Most often studied at the atomic & molecular level

Inorganic chemistry

Organic chemistry

Physical chemistry

Materials chemistry

Nuclear chemistry

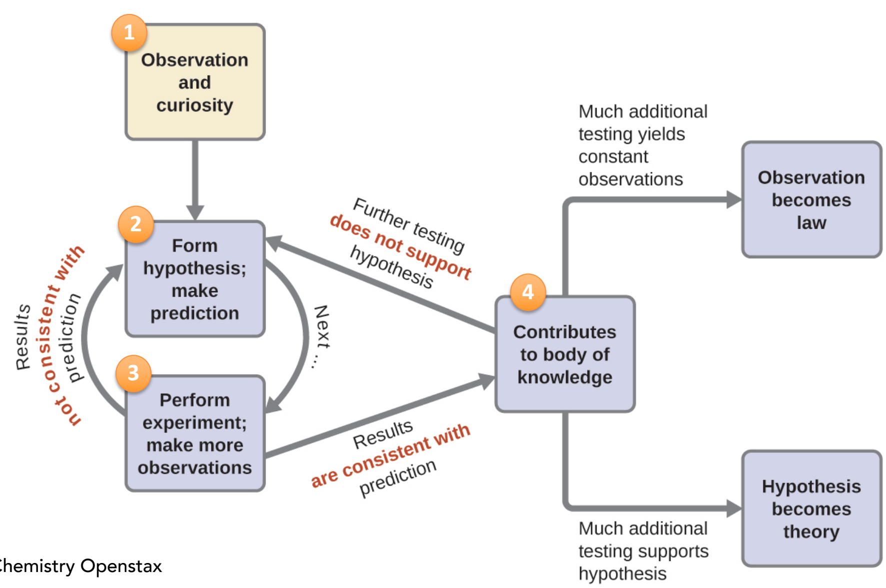
Chemical engineering

Biochemistry

Chemistry Openstax

The scientific method

Developed to ask and answer questions & explain observations.



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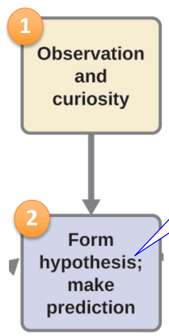
The scientific method

Developed to ask and answer questions & explain observations.



Hypothesis: a tentative explanation of an observation; educated guess

Hypotheses can be supported but **not proven**.
Why?
We can never know all potential causes of an observation or all the factors that contribute to the phenomenon we are observing.
Black swans: Until the 1600s Europeans believed that all swans were white. They were certain because they'd only ever seen white swans. Then Europeans found Australia and it's black swans. Whoops.

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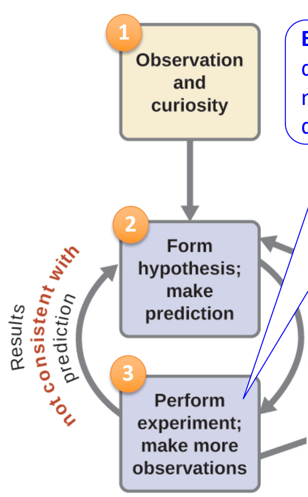
The scientific method

Developed to ask and answer questions & explain observations.



Experiment: a test done by collecting data; may support or disprove a hypothesis

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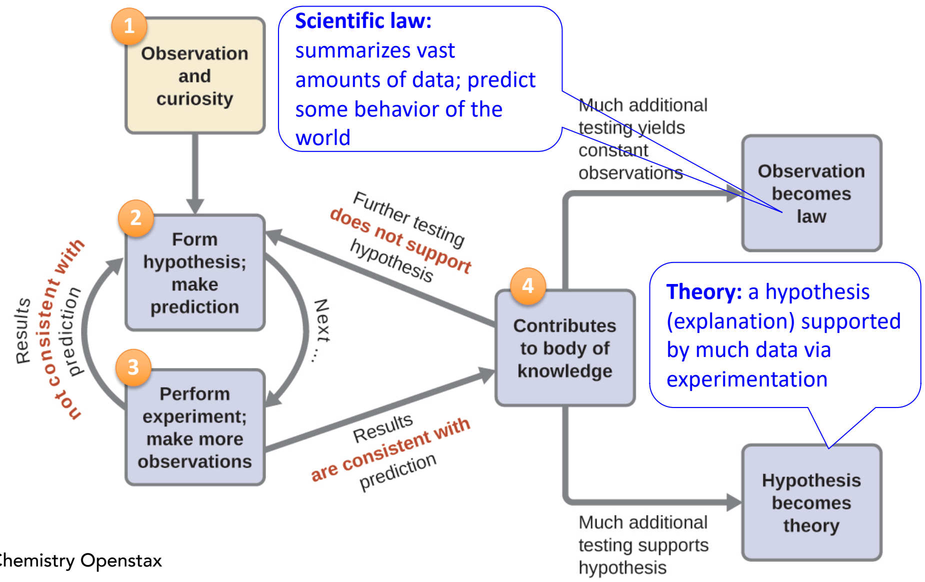
The scientific method

Developed to ask and answer questions & explain observations.



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Is once enough?

Nope!

While we can't prove hypotheses, scientists seek as much certainty as we can get using **repetition**.

Multiple trials repeat the experiment and collect enough data to allow us to use statistics to look for precision & accuracy.

- At least three trials are needed to calculate means & SDs.

Independent repetition: others repeat the experiment using multiple trials.

Same question different methods:
When we ask the same or similar questions with different methods we ensure that important results reflect the phenomenon and are not 'artifacts' of a particular method.

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The domains of chemistry

We'll be studying chemistry at a number of scales or **domains.**

Macroscopic: *scale of everyday life; large enough to see & touch*

Microscopic: *too small to see with the naked eye*

- Cells & viruses
- Molecules, ions, atoms & subatomic particles

Symbolic: *specialized language of symbols that represent components & processes of both macro- & microscopic domains*

- Elemental symbols
- Molecular formulas
- Arrows of chemical change

$$3NaCl + K3(PO4) \rightarrow Na3(PO4) + 3KCl$$

Can you?

(1) Describe a few ancient, but everyday, applications of chemistry?

(2) Explain why chemistry flourished during the Enlightenment?

(3) Explain critical differences between science & engineering?

(4) List the steps in the scientific method and describe how it's applied?

(5) Differentiate between a hypothesis and theory, and between a theory and a scientific law?

(6) Give examples of macroscopic, microscopic and symbolic domains of chemistry?

1. Essential ideas

1.2 Phases & classification of matter

- *Describe the basic properties of physical states*
- Define atoms & molecules
- Classify matter as elements, compounds, or homo- or heterogeneous mixtures
- Distinguish between mass & weight
- Apply the law of conservation of matter

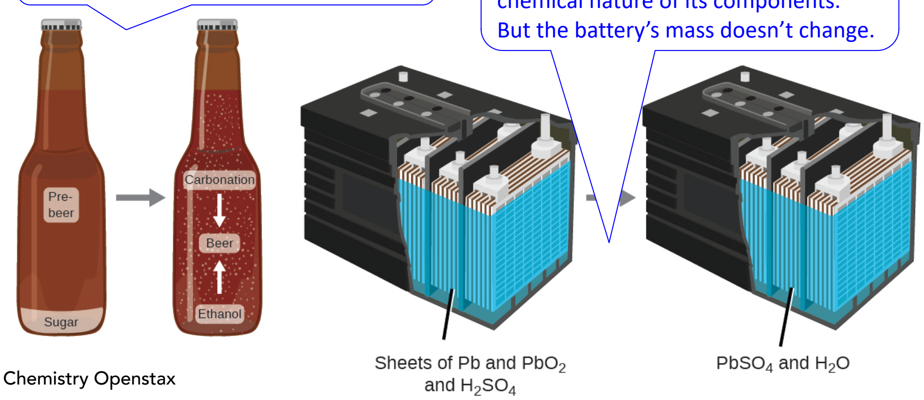
Law of conservation of mass

Much of what we do this semester will seek to obey the **law of conservation of mass:**

Mass is conserved, neither created nor destroyed…
by physical and chemical change.

Fermentation changes sugar to alcohol or CO2, but mass doesn't change

Redox reactions cause the battery to produce electric current & change the chemical nature of its components. But the battery's mass doesn't change.



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Atoms of elements

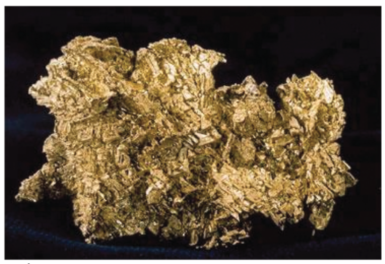
Atoms: *the smallest unit of matter that has the properties of that matter & can undergo chemical reaction*

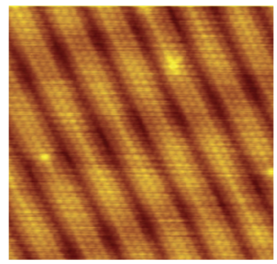
- *From the Greek atomos: indivisible or 'uncuttable'*

Atoms vs. elements?

- The periodic table has more than 100 elements.
- Each element has distinct physical & chemical properties.
- Each element can exist in varying amounts, and atom is the smallest amount of any element.

nugget of pure gold (Au)





Atoms of gold in a gold crystal (SEM)

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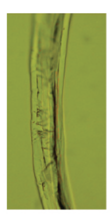
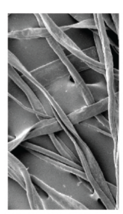
Atomic scale

cotton boll

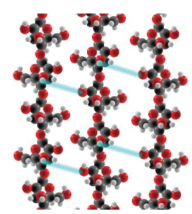
single strand of cotton (X40) 0.0001 cm



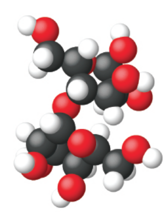
single strand of cotton (SEM, higher mag)



molecular model of cotton fiber



molecular close up showing atoms 1.5 E-8 cm each



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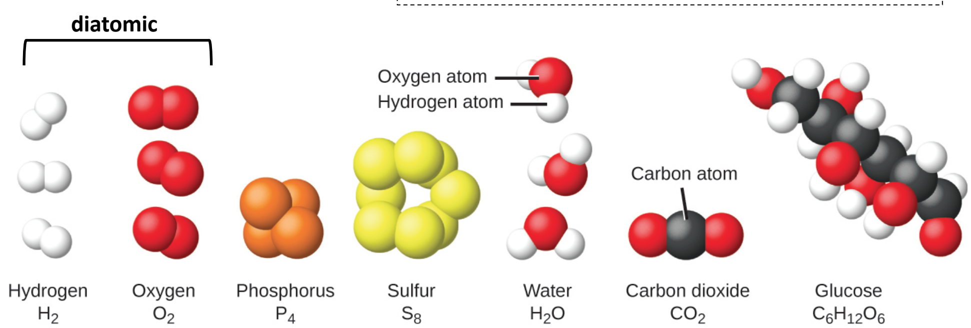
Molecules

Molecules: *two or more atoms combined at a constant ratio*
- *That's the law of constant composition*

Chemical bonds: *strong forces joining the atoms in molecules*

Molecular formulas: *the types & numbers of atoms in a molecule*

Note that some define molecules & compounds differently. I'm going to use these terms as synonyms.



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Classifying matter

Pure substance:
has constant composition

Element: can't be chemically broken down or simplified

Compound (molecule): can be chemically broken down into elements

Mixture:
has varying composition of elements or molecules

Homogenous: uniform throughout (smooth)
- Solution = liquid homogenous mixture

Heterogeneous: not uniform throughout (chunky)

Decomposition of molecules

Here's an example of how compounds or molecules can be broken down **(decomposed)** into simpler compounds or elements by a chemical reaction:

$$2HgO\,(s) + heat \rightarrow 2Hg\,(l) + O_2\,(g)$$

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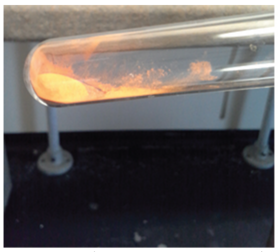
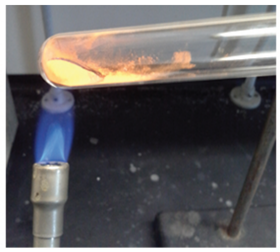


HgO (mercury II oxide)



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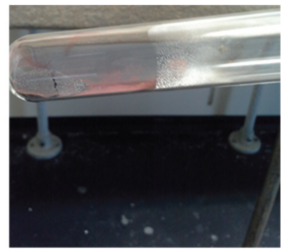
adding heat to cause decomposition



Hg(l)+ O_2(g)

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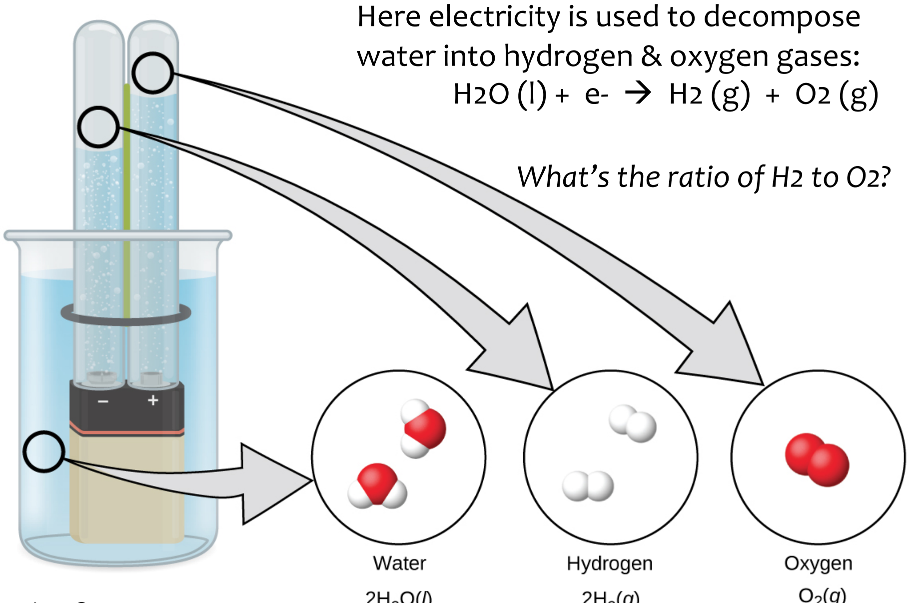
Physical decomposition

Here electricity is used to decompose water into hydrogen & oxygen gases:

$$H_2O\,(l) + e^- \rightarrow H_2\,(g) + O_2\,(g)$$

What's the ratio of H_2 to O_2?



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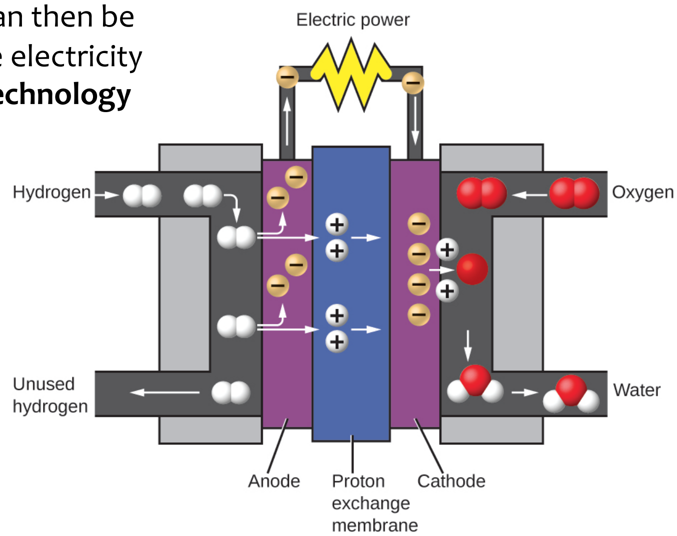
Practical application: fuel cells

Electrolysis of water can be used to store electricity as hydrogen gas.

Hydrogen gas can then be used to produce electricity using **fuel cell technology**



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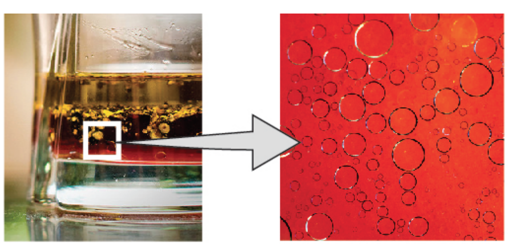
Homo- vs. heterogeneous mixtures

heterogeneous mixture



A salad dressing of oil & vinegar has distinct & visible parts.

- As the mixture settles droplets of oil are visible.

homogenous mixture

Sports drink solutions are uniform throughout.

Mixtures occur in all physical states. ***Examples***? 3

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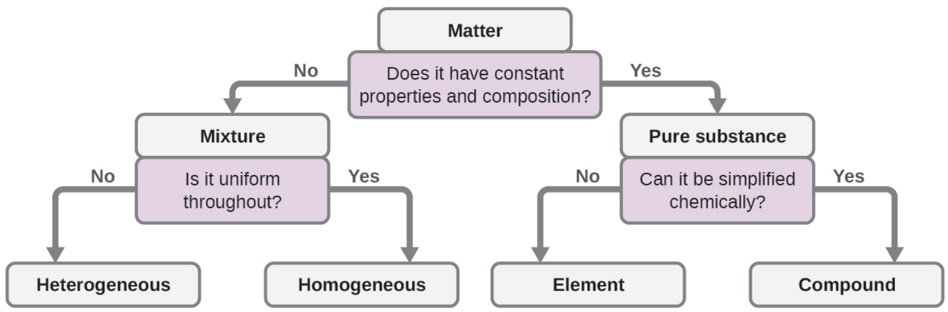
Ask yourself these questions

During this course you may find it useful to organizing information into **flowcharts**, **lists of steps**, or using **diagrams** like this one.



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Can you?

(1) Differentiate between the physical states of matter?

(2) Explain the difference between mass and weight?

(3) Explain why the law of conservation of mass is particularly important to chemistry?

(4) Define and differentiate between atoms, elements & molecules?

(5) Differentiate between pure substances & mixtures?

(6) Differentiate between homogeneous & heterogeneous mixtures?

1. Essential ideas

1.3 Physical & chemical properties

- Identify properties & changes in matter as physical or chemical
- Identify properties of matter as extensive or intensive

Physical properties & changes

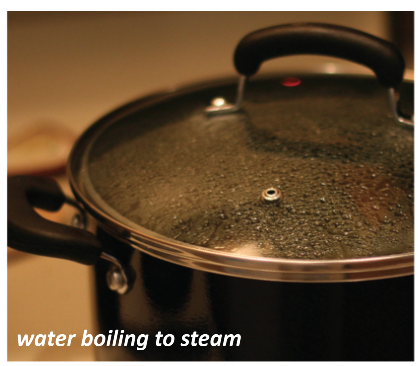
Physical properties: *a property or characteristic not associated with change of identity of chemical composition*

- Density, color, hardness, melting & boiling points, magnetism

Physical changes: *changes in state or physical property without changes in identity or chemical composition*

melting wax

Chemistry Openstax



water boiling to steam

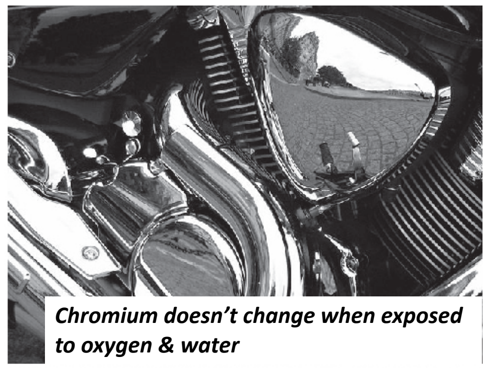
Chemical properties & changes

Chemical properties: *a property that governs the ability of a substance to change (or not) its identity of chemical composition*

- Combustion, reduction-oxidation, precipitation, neutralization

Chemical changes: *changes of chemical identity by reaction with another substance*

Iron rusts when exposed to oxygen & water



Chromium doesn't change when exposed to oxygen & water

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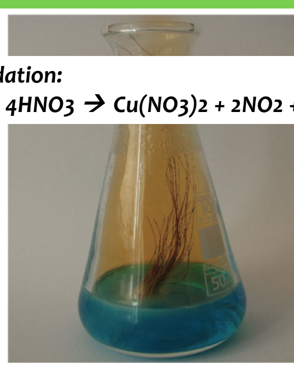
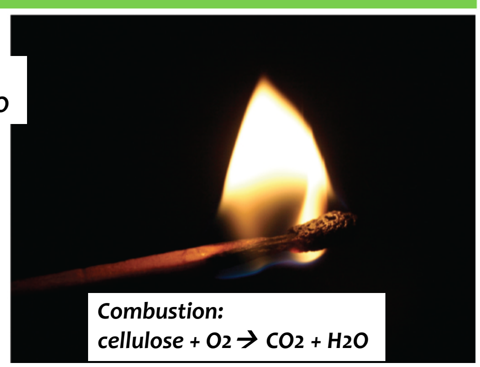
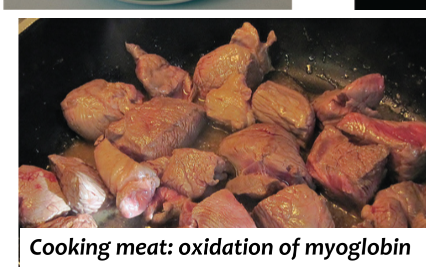
Chemical reactions



Oxidation:
$Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$



Combustion:
cellulose $+ O_2 \rightarrow CO_2 + H_2O$



Cooking meat: oxidation of myoglobin

Over-ripening of bananas

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Intensive vs. extensive properties

Extensive properties: *properties dependent on mass & volume*

Consider 10 drops vs. 10 liters of gasoline.

- Both can be combusted in the presence of oxygen.
- The amount of energy released is depends on volume combusted.

Intensive property: *properties that don't depend on mass & volume*

Consider a steel ball bearing & a one-ton block of steel. What properties do they share?

- Density, hardness, conductivity, melting point

What are some extensive & intensive properties of people? 4

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Can you?

(1) Define physical & chemical properties?

(2) Describe the difference between physical & chemical changes?

(3) Differentiate between intensive & extensive physical properties?

1. Essential ideas

1.4 Measurements

- Explain the process of measurement
- Identify three basic parts of a measure of quantity
- Describe the properties & units of length, mass, volume, density, temperature & time
- Perform basic unit calculations & conversions

Every measurement has three parts

In science, every measurement has **three essential elements:**

Number or value 226.0

Unit g (grams)

Uncertainty

226.0 ± 0.1 g

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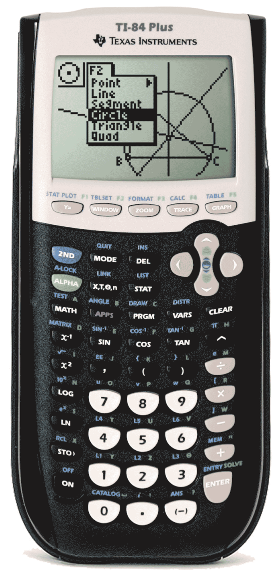
Scientific notation

Scientific notation allows us to express very large or small values while focusing on significant digits.



The maximum takeoff weigh of a jet is: 5

298,000 kg $\quad$ 2.98×10^5 kg

2.98 E5 kg

The average weight of a mosquito is: 6

0.0000025 kg $\quad$ 2.5×10^{-6} kg

2.5 E-6 kg

What's the best way to use a calculator for scientific notation? 7

Use EE! I strongly advise against the '^'.

Units

Science uses the **metric system**, or **SI units**.

quantity	unit	symbol
length	meter	m
mass	gram	g
time	second	s
temperature	Celsius / Kelvin	C / K
amount	mole	mol

The Kelvin scale is used to measure the temperature of gases.

Kevin = Celsius + 273.15

Unit prefixes

Unit prefixes can be used in place of scientific notation.

Express these with unit prefixes instead of scientific notation: 8

8 E9 years	8 Gyr
3,000,000 Hz	3 MHz
2 E-3 moles	2 mmol
1 E-6 L	1 µL

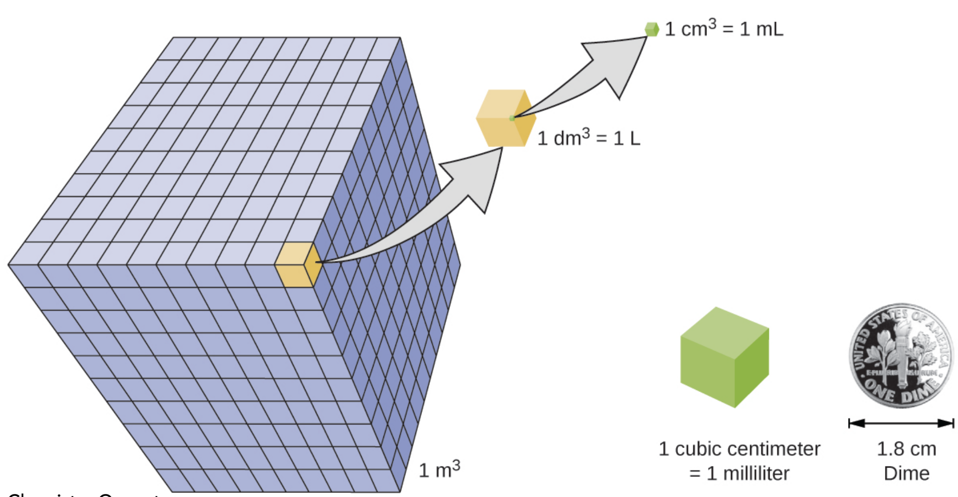
prefix	symbol	factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Notice the pattern?
Exponents change by 3.

Derived units

Derived unit are created by combining SI units.

- **Volume** can be expressed as a cubic length.



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Density

Density: *the ratio of mass to volume (g/mL)*

$$\text{density } (\rho) = \frac{\text{mass}}{\text{volume}}$$

Is density an intensive or extensive property? Why? 9

solids (g/mL)		liquids (g/mL)		gases (g/L)	
ice	0.92	water	1.0	dry air	1.20
oak	0.60- 0.90	ethanol	0.79	oxygen	1.31
iron	7.9	acetone	0.79	nitrogen	1.14
copper	9.0	glycerin	1.26	CO_2	1.80
lead	11.3	olive oil	0.92	helium	0.16
silver	10.5	gasoline	0.70-0.77	neon	0.83
gold	19.3	mercury	13.6	radon	9.1

Notice that the density of **gases** is measured in **g/L** as it's significantly lower.

Calculating density

What is the density of a cube of lead each side of the cube measures 2.00 cm and the cube's mass is 90.7 g? 10

volume = cubic length = $(2.00 \text{ cm})^3 = 8.00 \text{ cm}^3$

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{90.7 \text{ g}}{8.00 \text{ cm}^3} = 11.3 \text{ g/cm}^3$$

What is the volume of a cube with edge lengths of 0.843 cm? 11

volume = cubic length = $(0.834 \text{ cm})^3 = 0.599 \text{ cm}^3$

If the mass of that cube is 5.34 g, what is the density of the cube? 12

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{5.34 \text{ g}}{0.599 \text{ cm}^3} = 8.91 \text{ g/cm}^3$$

Can you?

(1) Describe the three parts of any measurement?

(2) Convert numbers in and out of scientific notation?

(3) Replace scientific notation with metric prefixes?

(4) Relate density to mass and volume and solve for any of the three given the other two?

1. Essential ideas

1.5 Measurement, uncertainty, accuracy & precision

- Define accuracy & precision
- Distinguish exact & inexact numbers
- Correctly represent uncertainty in quantities using significant figures
- Apply proper rounding rules to computed quantities

Exact vs. inexact numbers

Exact numbers don't have uncertainty.

1. Counted values: 5 books on the table
1. Conversion factors: 12 inches / foot

Because they are exact, conversion factors don't affect significant figures.

What about enormous numbers? 13
- *Grains of sand on a beach?*
- *Stars in the sky?*

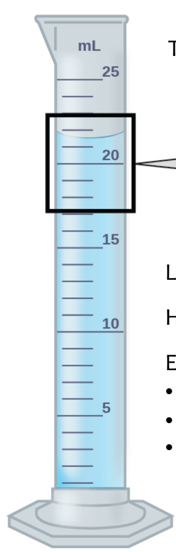
Inexact numbers: *measured by instruments*
- Inexact numbers have uncertainty.

Imagine that I gave each student in class the same Stanley measuring tape and asked each to measure the dimensions of the room.

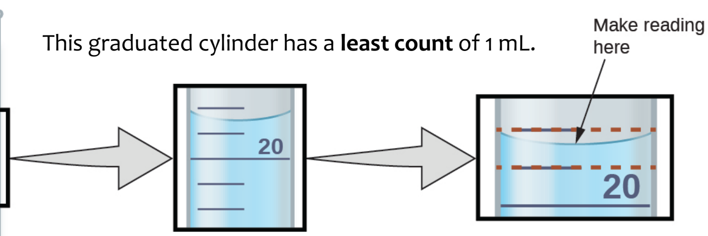
Would all the measurements be the same? 14

Uncertainty in measurement

Significant digits communicate the degree of uncertainty of instruments used to make measurements.



This graduated cylinder has a **least count** of 1 mL.



Liquid volumes are measured at the bottom of the curving **meniscus**.

Here, greater than 21 but less than 22, so what do you record?

Estimate the fraction of the least count, here the fraction of 1 mL.
- I'd call it 21.7 mL but others might disagree.
- So we add the **uncertainty** ± ½ of the least count.
- Thus, 21.7 ± 0.5 mL.

3 significant digits

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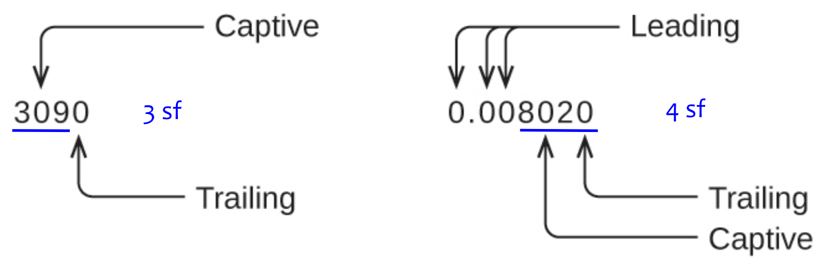
Significant digits

Rules for significant digits:

1. All **non-zero** digits are significant.
2. **Zeros** are sometimes significant:
   - Leading: never
   - Captive (trapped): always
   - Trailing: only when following a decimal



3.09 E3

8.020 E-3

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Calculating with significant digits

1. **Multiplication & division: least sf rules!**

The answer has only as many sf as the value with the lowest sf.

(6.221 cm)(5.2 cm) = 32.3492 cm^2 -> **32** cm^2

2. **Addition & subtraction: limit number of sf after the decimal**

So the number of digits following the decimal is limited by the value in the calc with fewest sf after the decimal.

20.4 + 1.322 + 83 = 104.722 -> **105**

There are 1609.344 m in 1 mile. How many meters in 1.35 miles?

$\frac{1.35 \text{ miles} \quad 1609.344 \text{ m}}{1 \text{ mile}}$ = 2172.6144 m --> **2.17** E3 m 15

$\frac{(64.2 + 7.9)}{220.3}$ 16 $\frac{71.2}{220.3}$ = **0.327**

Example

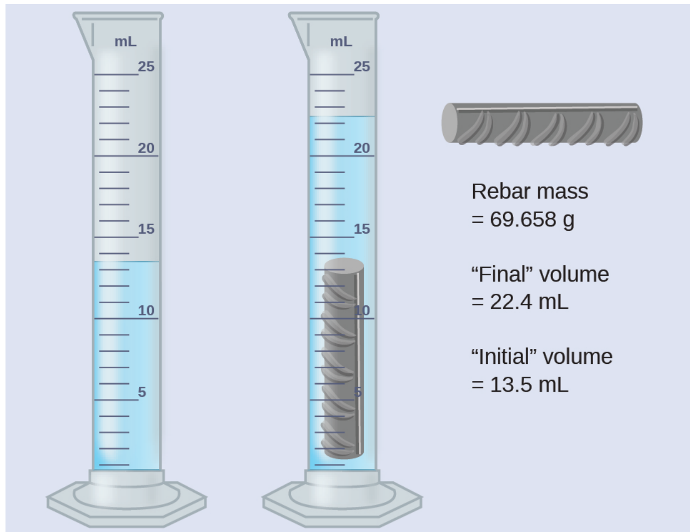
Using the data provided here, calculate the density of the rebar with the proper number of significant digits. 17

volume = Vf – Vi

22.4 – 13.5 = 8.9 mL

ρ = m/v

$\frac{69.658 \text{ g}}{8.9 \text{ mL}} = 7.8$ g/mL



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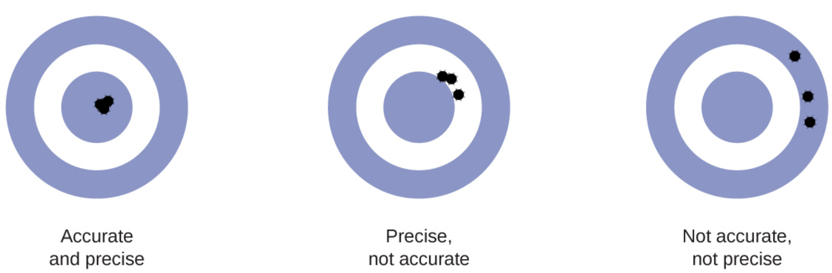
Accuracy vs. precision

Accurate: *close to the true or accepted value*

Precision: *repeated values that are very close to one another*



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Accuracy vs. precision

A pharmaceutical QA/QC tech checks the accuracy & precision of three machines that dispense 296 mL of cough syrup per bottle. She makes measurements in triplicate.

machine 1 (mL)	machine 2 (mL)	machine 3 (mL)
283.3	298.2	296.1
284.1	294.2	295.9
283.9	296.0	296.1
284.0	297.8	296.0
284.1	293.9	296.1

How do the machines compare in terms of accuracy & precision?

18

1. Good precision, poor accuracy
2. Better accuracy, poor precision
3. Fairly precise & accurate

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Can you?

(1) Explain the difference between exact & inexact numbers and give examples of each?

(2) Explain how to measure the volume of a liquid using the meniscus, the instrument's least count & the digit of uncertainty?

(3) Describe when zeros are significant and when they are not.

(4) Describe the rules for multiplying & dividing vs. adding & subtracting with significant figures.

(5) Define differentiate between accuracy and precision.

1. Essential ideas

1.6 Mathematical treatment of measurement results

- Explain the dimensional analysis approach
- Use dimensional analysis for unit conversions

Conversion factors

Conversion factors: *ratios of the same quantity expressed in two different units*

- Conversion factors are equal to one
- 'Flippable'
- No sig figs

$$\frac{2.54\ \text{cm}}{1\ \text{inch}} \qquad \frac{1\ \text{inch}}{2.54\ \text{cm}}$$

Conversion factors

METRIC CONVERSION FACTORS

Prefix	Abbreviation	Conversion Factor		For Example…	For Example…
Mega-	M	1000000	10^{6}	1 Megabyte = 1 x 10^{6} bytes	1 byte = 10^{-6} Megabytes
kilo-	k	1000	10^{3}	1 kilometer = 1000 meters	1 meter = 0.001 kilometers
deci-	d	0.1	10^{-1}	1 deciliter = 0.1 liters	1 liter = 10 deciliters
centi-	c	0.01	10^{-2}	1 centimeter = 0.01 meters	1 meter = 100 centimeters
milli-	m	0.001	10^{-3}	1 milliliter = 0.001 liters	1 liter = 1000 milliliters
micro-	µ	0.000001	10^{-6}	1 microgram = 10^{-6} grams	1 gram = 10^{6} micrograms
nano	n	0.000000001	10^{-9}	1 nanometer = 10^{-9} meters	1 meter = 10^{9} nanometers
pico	p	0.000000000001	10^{-12}	1 picometer = 10^{-12} meters	1 meter = 10^{12} picometers

OTHER CONVERSION FACTORS AND CONSTANTS

Weight/Mass	Volume	Length/Distance
16 ounces = 1 pound 1 kilogram = 2.2 pounds 454 grams = 1 pound 1 ton = 2000 pounds	1 liter = 1.0567 quarts 1 mL = 1 cm^3 1 gallon = 3.78 liters 1 gallon = 4 quarts = 128 fluid ounces 1 quart = 2 pints = 32 fluid ounces 1 pint = 2 cups = 16 fluid ounces	1 inch = 2.54 centimeters 1 mile = 5280 feet = 1.609 kilometers 1 yard = 3 feet = 36 inches = 0.9144 meters 1 meter = 39.37 inches = 3.281 feet = 1.094 yards 1 kilometer = 1094 yards = 0.6215 miles

Density of Water: 1.00 g/mL

Energy: 1 cal = 4.184 J

Time
1 year = 365 days = 12 months = 52 weeks
1 day = 24 hours
1 hour = 60 minutes
1 minute = 60 seconds

Temperature
$°C = \frac{5}{9}(°F - 32)$ and $°F = \left(°C \cdot \frac{9}{5}\right) + 32$
Kelvins = °C + 273.15

Pressure Units: 1 atm = 760 mmHg = 101.325 kPa = 101325 Pa = 1.01325 bar = 14.7 psi = 29.92 inches Hg

Useful Constants:
Avogadro's Number (N_A) = 6.02 x 10^{23} items / mole
Ideal Gas Constant (R) = 0.0821 $\frac{L \cdot atm}{mol \cdot K}$
Speed of Light (c) = 3.00 x 10^{8} m/s
Planck's Constant (h) = 6.63 x 10^{-34} J • s

Railroad track method

The **"railroad track" method** lines up conversion factors so old units cancel diagonally leaving only the desired new unit.

1. Start at the left with the value with one unit.
2. Write the desired final unit at the right as the goal.
3. Look for a conversion factor with both units.
4. 'Flip' the conversion factors so that units match diagonally.
5. Check to see that the unit matches the goal

$$\cancel{\text{old unit}} \; \frac{\text{new unit}}{\cancel{\text{old unit}}} = \text{new unit}$$

Multiply by non 1s above the line, divide by non 1s below the line.

The mass of a frisbee is 125 grams. Convert that mass to ounces.

$$125\,\cancel{g} \; \frac{1\ \cancel{lb}}{454\ \cancel{g}} \; \frac{16\ oz}{1\ \cancel{lb}} = 4.41\ oz \qquad oz$$

19

Apply the steps:

Convert a volume of 9.345 quarts to liters.

20

1. Start at the left with the value with one unit.
2. Write the desired final unit at the right as the goal.
3. Look for a conversion factor with both units.
4. ‘Flip’ the conversion factors so that units match diagonally.
5. Check to see that the unit matches the goal

$$\frac{9.345\ \cancel{qt}}{} \;\frac{1\ L}{1.0567\ \cancel{qt}} = 8.844\ L \qquad L$$

More than one factor:

A 4.00-quart sample of antifreeze weighs 9.26 pounds.
What is the density of the antifreeze in units of g/mL?

21

1. Start at the left with the value with one unit.
2. Write the desired final unit at the right as the goal.
3. Look for a conversion factor with both units.
4. ‘Flip’ the conversion factors so that units match diagonally.
5. Check to see that the unit matches the goal

$\rho = m/v$

$$\frac{4.00\ \cancel{qt}}{} \;\frac{1\ \cancel{L}}{1.0567\ \cancel{qt}} \;\frac{1\ E3\ mL}{1\ \cancel{L}} = 3.79\ E3\ mL \qquad mL$$

$$\frac{9.26\ \cancel{lb}}{} \;\frac{454\ g}{1\ \cancel{lb}} = 4.20\ E3\ g \qquad g$$

$$\rho = \frac{m}{v} = \frac{4.20\ E3\ g}{3.79\ E3\ mL} = 1.11\ g/mL$$

More complexity

When driven the 1250 km from Philadelphia to Atlanta, a Lamborghini Aventador Roadster uses 213 L of gas.

22

a) *What is the average mileage of the roadster (mpg)?*
b) *What is the cost of the trip when gas costs $2.50 per gallon?*

Strategy: 1) km → miles
2) L → gallons
3) gallons → $

$$\frac{1250\ \cancel{\text{km}}}{} \cdot \frac{1\ \text{miles}}{1.6093\ \cancel{\text{km}}} = 777\ \text{miles} \qquad \text{miles}$$

$$\frac{213\ \cancel{\text{L}}}{} \cdot \frac{1\ \text{gallon}}{3.78541\ \cancel{\text{L}}} = 56.3\ \text{gallons} \qquad \text{gallons}$$

$$\frac{777\ \text{miles}}{56.3\ \text{gallons}} = 13.8\ \text{mpg} \qquad \frac{56.3\ \cancel{\text{gallons}}}{} \cdot \frac{\$2.50}{1\ \cancel{\text{gallon}}} = \$141$$

Changing both units

The average speed of a nitrogen molecule in air at 25°C is 515 m/s. *Convert this speed to miles/hour.*

22

Strategy: 1) m → km → miles
2) seconds → minutes → hours

$$\frac{515\ \cancel{\text{m}}}{1\ \cancel{\text{s}}} \cdot \frac{1\ \cancel{\text{km}}}{1\ \text{E3}\ \cancel{\text{m}}} \cdot \frac{1\ \text{miles}}{1.6093\ \cancel{\text{km}}} \cdot \frac{60\ \cancel{\text{s}}}{1\ \cancel{\text{min}}} \cdot \frac{60\ \cancel{\text{min}}}{1\ \text{hr}} \qquad \frac{\text{miles}}{\text{hour}}$$

$$= \frac{1.15\ \text{E3 miles}}{\text{hour}}$$

Cubing conversion factors

23

What is the mass (g) of a piece of gold that's 2 inches on each side?
The density of gold is 19.3 g/cm³.

Strategy: in → in³ → cm³ → g

Note: you must cube both the values & units of conversion factors!

$$\frac{2^3\ \cancel{in^3}}{} \cdot \frac{2.54^3\ \cancel{cm^3}}{1^3\ \cancel{in^3}} \cdot \frac{19.3\ g}{1\ \cancel{cm^3}} = 2530.2 \rightarrow 3\ E3\ g \quad g$$

Try cubing

The Earth's oceans contain 1.36×10^9 km³ of water. Convert to liters!

23

$\frac{1\ L}{1\ E\text{-}3\ m^3}$

Strategy: km³ → m³ → L

$\frac{1\ E3\ m}{1\ km}$

Note: you must cube both the values & units of conversion factors!

$$\frac{1.36\ E9\ \cancel{km^3}}{} \cdot \frac{(1\ E3)^3\ \cancel{m^3}}{1^3\ \cancel{km^3}} \cdot \frac{1\ L}{1\ E\text{-}3\ \cancel{m^3}} = 1.36\ E21\ L \quad L$$

Can you?

(1) Create conversion factors from word problems and balanced chemical equations?

(2) Create a problem solving strategy by identifying conversion factors and ordering them to convert units from given to desired

(3) Set up railroad tracks, using units to create a conversion process?

(4) Remember to cube both units and numbers when cubing lengths to create volumes?

Module 1, Introduction: Terms to know

accuracy
atom
Celsius
chemical change
chemical property
chemistry
compound
density
dimensional analysis
element
exact number
extensive property
gas
heterogeneous
homogeneous
hypothesis
intensive property
Kelvin
law
law of conservation of mass
liquid
macroscopic domain
mass
matter
microscopic domain
mixture
molecule
physical change
physical property
plasma
precision
pure substance
scientific method
significant figure
solid
symbolic domain
theory
uncertainty
volume
weight