Chapter 1
Chemistry: The Science of Change

Phoenix.gov

The science that studies the properties of substances & how substances react with one another.

How stuff works on a molecular/atomic/subatomic level
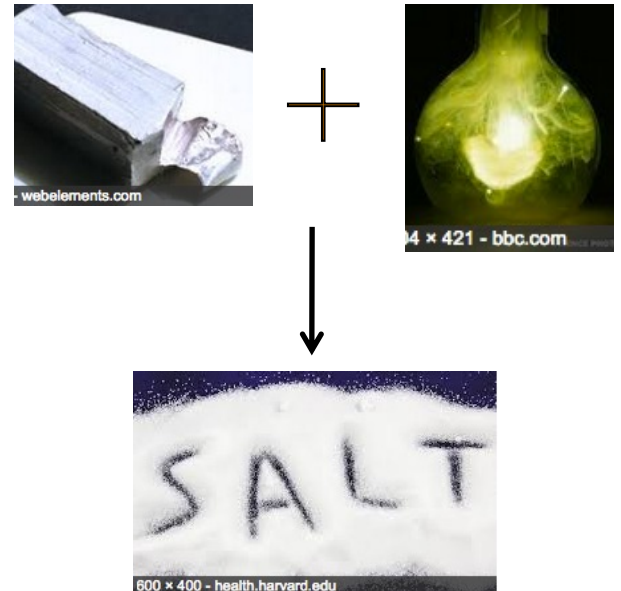
Chemistry!

MATTER

Has mass & takes up space

ENERGY

The capacity to do work or cause change

REACTIONS

How materials interact & change

+

webelements.com

4 × 421 - bbc.com

SALT

600 × 400 - health.harvard.edu

Learning the Language

Chemistry describes materials and predicts behavior using three basic concepts

Composition: What is in a material
- Mass percent of elements/compounds
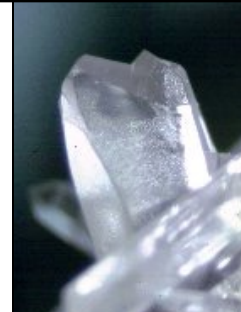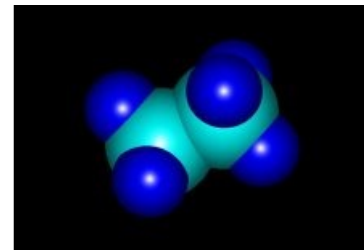- Atomic/molecular ratios within material
- Stoichiometry

Structure
- Molecular/ionic/atomic arrangement
- Phase (solid, liquid, gas)
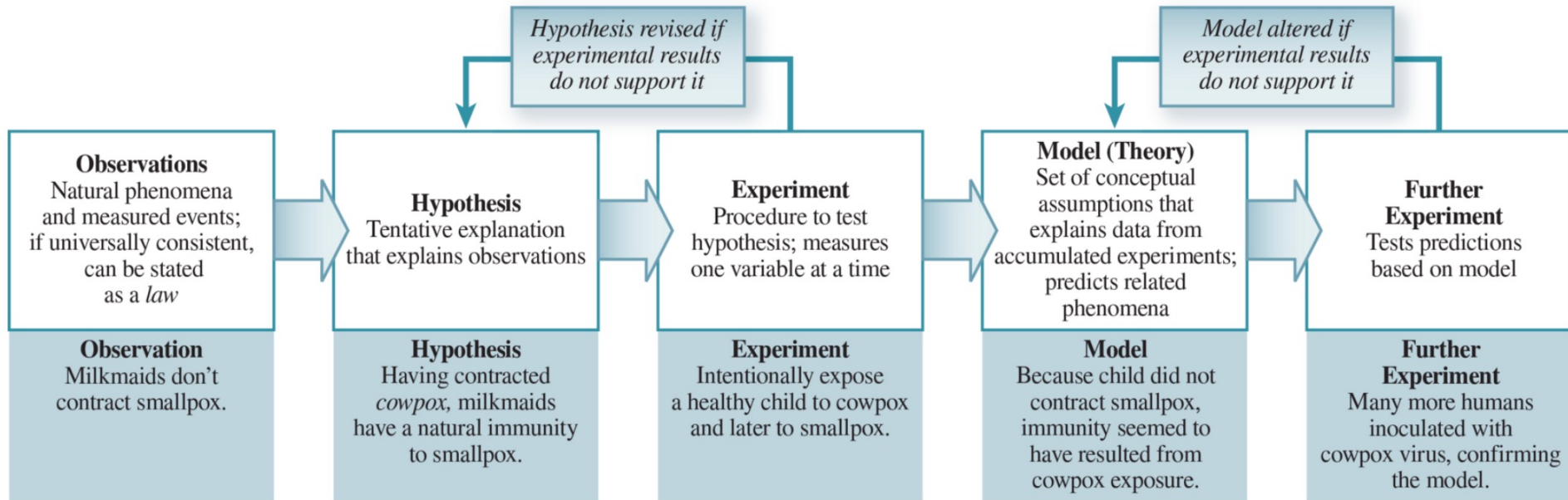
Properties – chemical & physical
- Specific to a particular material
- ex: boiling point, color, odor, reactivity
- Used for identification

Often looking at materials at the submicroscopic level – too small to see with the human eye

The Scientific Method
Series of steps that explain an observation

Observations
Natural phenomena and measured events; if universally consistent, can be stated as a *law*

Hypothesis
Tentative explanation that explains observations

Hypothesis revised if experimental results do not support it

Experiment
Procedure to test hypothesis; measures one variable at a time

Model (Theory)
Set of conceptual assumptions that explains data from accumulated experiments; predicts related phenomena

Model altered if experimental results do not support it

Further Experiment
Tests predictions based on model

Observation
Milkmaids don't contract smallpox.

Hypothesis
Having contracted *cowpox*, milkmaids have a natural immunity to smallpox.

Experiment
Intentionally expose a healthy child to cowpox and later to smallpox.

Model
Because child did not contract smallpox, immunity seemed to have resulted from cowpox exposure.

Further Experiment
Many more humans inoculated with cowpox virus, confirming the model.

Exposure to a virus can enable humans to build an immunity to that virus – enabled the development of vaccines
Most vaccines today use inactivated viruses - safer
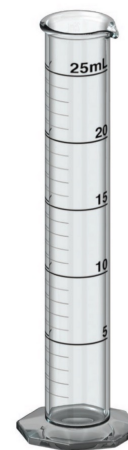
Measurements

Determining how much matter is present

olin.edu

Base Units of Measurement International System of Units (SI)

TABLE 1.1	Base SI Units	
Base Quantity	**Name of Unit**	**Symbol**
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

$$K = °C + 273.15$$

Will be used frequently in CHM 101; you are expected to know them! (Depending on other classes, will likely need to know ampere in the future.)

SI Prefixes
Yes, you need to know these too

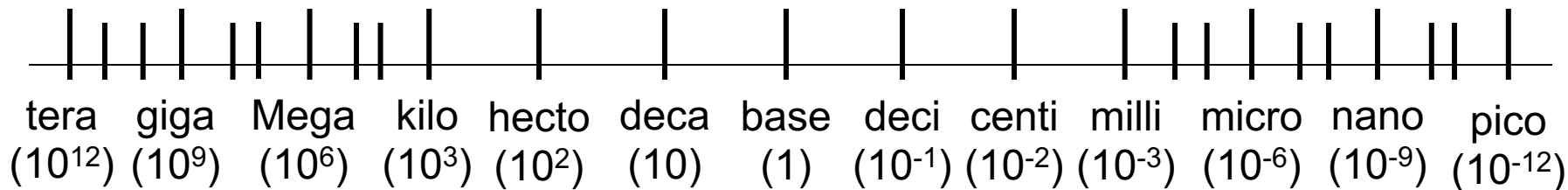| TABLE 1.2	Prefixes Used with SI Units		
Prefix	**Symbol**	**Meaning**	**Example**
Tera-	T	1×10^{12} (1,000,000,000,000)	1 teragram (Tg) = 1×10^{12} g
Giga-	G	1×10^{9} (1,000,000,000)	1 gigawatt (GW) = 1×10^{9}
Mega-	M	1×10^{6} (1,000,000)	1 megahertz (MHz) = 1×10^{6}
Kilo-	k	1×10^{3} (1,000)	1 kilometer (km) = 1×10^{3} m
Deci-	d	1×10^{-1} (0.1)	1 deciliter (dL) = 1×10^{-1} L
Centi-	c	1×10^{-2} (0.01)	1 centimeter (cm) = 1×10^{-2} m
Milli-	m	1×10^{-3} (0.001)	1 millimeter (mm) = 1×10^{-3} m
Micro-	μ	1×10^{-6} (0.000001)	1 microliter (μL) = 1×10^{-6} L
Nano-	n	1×10^{-9} (0.000000001)	1 nanosecond (ns) = 1×10^{-9} s
Pico-	p	1×10^{-12} (0.000000000001)	1 picogram (pg) = 1×10^{-12} g

hecto (10^2)
deca (10^1)
Base

The Great Majestic King Henry Died By Drinking Chocolate Milk at Mad Nick's Palace

The **G**reat **M**ajestic **K**ing **H**enry **D**ied **B**y **D**rinking **C**hocolate **M**ilk at **M**ad **N**ick's **P**alace

Metric System is Base 10 – essentially just moving the decimal point

| tera (10^{12}) | giga (10^9) | Mega (10^6) | kilo (10^3) | hecto (10^2) | deca (10) | base (1) | deci (10^{-1}) | centi (10^{-2}) | milli (10^{-3}) | micro (10^{-6}) | nano (10^{-9}) | pico (10^{-12}) |

$1\ Tm = 1 \times 10^{12}\ m$

$1\ Gm = 1 \times 10^9\ m$

$1\ Mm = 1 \times 10^6\ m$

$1\ km = 1{,}000\ m$

$1\ hm = 100\ m$

$1\ dam = 10\ m$

$1\ m = 1\ m$

$10\ dm = 1\ m$

$100\ cm = 1\ m$

$1000\ mm = 1\ m$

$1 \times 10^6\ \mu m = 1\ m$

$1 \times 10^9\ nm = 1\ m$

$1 \times 10^{12}\ pm = 1\ m$

Metric Conversion Examples

1.) Convert 256.74g to kg
(0.25674 kg)

2.) How many milliliters are in 3.78 L?
(3780 mL)

3.) Convert 18000000 cm into Mm
(0.18 Mm)

Derived Units: Volume

SI derived unit for volume is a cubic meter (m³)
Common unit is a "**Liter (L)**"

$$1L = 1000cm^3 = \frac{1000cm}{1}\ x\ \frac{1cm}{1}\ x\ \frac{1cm}{1}\ x\ \frac{1m}{100cm}\ x\ \frac{1m}{100cm}\ x\ \frac{1m}{100cm} = 1x10^{-3}m^3$$

1 L ≠ 1 m³

1L = 1x10⁻³m³

1 mL = 1 cm³

1cm

1cm

1cm

1 liter

Volumetric flask
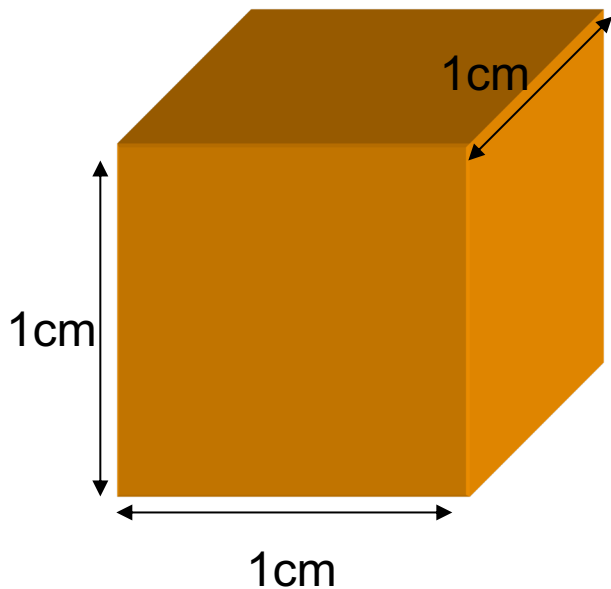
Metric Conversions with Units that are squared (s²), cubed (cm³), etc. can be tricky:

ex.) Convert 87856 cm³ to m³

Note: 1 m = 100 cm but 1m³ ≠ 100 cm³
Need to do the conversion 3x for cubed numbers
(2x for squared, etc.)

87856 cm³ = 0.087856 m³

Derived Units: Density

Density: Ratio of mass to volume of a material

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{m}{V}$$

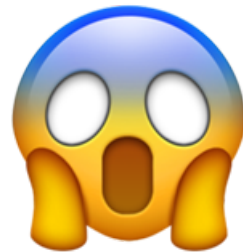SI derived unit for density is kg/m³

1 g/cm³ = 1 g/mL = 1000 kg/m³

Substance	Density (g/cm³)
Air*	0.001
Ethanol	0.79
Water	1.00
Mercury	13.6
Table salt	2.2
Iron	7.9
Gold	19.3

Intensive property
- Can be used to identify a material
- Units of mass and volume may vary

Handling Numbers

Math Review

😱

Significant Figures:
Number of Digits to Report in Final Answer

1. All non-zero digits are significant

2. Use decimal point to decide if zeros are significant

Between 2 numbers	significant	50.002	5 sig figs
Before decimal point	not significant	0.502	3 sig figs
Before the first digit	not significant	0.0052	2 sig figs
End of # after decimal	significant	0.0200	3 sig figs
No decimal point:	not significant	500	1 sig fig

3. **Exact** numbers have unlimited number of sig. figs.

Inherently an integer: e.g. 4 sides to a square

Inherently a fraction: e.g. ½ of a pie

Obtained by counting: e.g. 47 people in a class

Defined quantity: e.g. 12 eggs in a dozen

Determining the correct number of significant figures (sigfigs) in math problems:
Answer is based on the LEAST significant value

Addition/subtraction – Sig figs based on decimal

$$\begin{array}{r} 150\underline{0} \\ +\ 2976 \\ \hline 44\textcolor{cyan}{76} \end{array} \longrightarrow 4500$$

$$\begin{array}{r} 12.45\textcolor{cyan}{XX} \\ -\ \ 9.2680 \\ \hline 3.18\textcolor{cyan}{20} \end{array} \longrightarrow \textcolor{red}{3.18}$$

Multiplication/Division – Sig figs based on all sig digits

4 sig figs   3 < 4 so 3 sig figs

$$3.182 \times 3.57 = 11.3\textcolor{cyan}{5974} \longrightarrow \textcolor{red}{11.4}$$

3 sig figs

Rounding is based on number after last sigfig:
≥ 5 round up ≤ 5 round down

Multiple math functions – follow order of ops

$$(12.45 - 9.2680) \times 3.575 = 11.37565$$

Step one: Subtraction → Sigfigs based on decimal

$(12.\underline{45} - 9.\underline{2680}) = 3.182$

2 sigfigs after decimal

3 sigfigs overall in final answer

$$\begin{array}{r} 12.45XX \\ - \quad 9.2680 \\ \hline \mathbf{3.18}20 \end{array}$$

Step two: Multiplication → Sigfigs based on all sig digits

$$\mathbf{3.18}2 \ \times 3.575 = \mathbf{11.3}7565$$

3 sigfigs in 1st number, 4 in 2nd → 3 in final answer
Here addition limits sigfigs

Round up because the next number is >5

$$11.37565 \rightarrow \boxed{11.4}$$

Why do significant figures matter?

123.52 cm
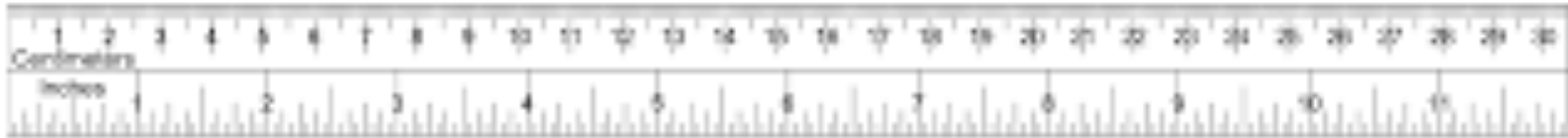
121 cm
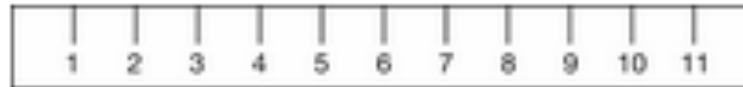
Width of room: 244.6 cm
Will the two desks fit?

$$\begin{array}{r} 123.52 \text{ cm} \\ + \ 121.?? \text{ cm} \\ \hline 244.52 \text{ cm} \end{array}$$

245 cm

What if this is actually 121.1?!?

Fitting desks in a room may not seem all that important – but the same concept is true for the design of buildings & bridges!

Scientific Notation

For very large or very small numbers

Significant digits $\longrightarrow$ **1.7 x 10^6** $\leftarrow$ Size of number (multiplier)

$1700000 \rightarrow 1.7 \times 10^6$ $\longleftarrow$ Positive exp = large number (>1)

$0.0000017 \rightarrow 1.7 \times 10^{-6}$ $\longleftarrow$ Negative exp = small number (<1)

Rules:
- Keep all significant numbers
- Place decimal after 1st significant number (1.7)
- To get exponent:
  - Count number of places decimal moved to get to correct location (after 1st significant number). This value is your exponent.
  - If the number is >1, exp is positive $1700000 \rightarrow 1.7 \times 10^6$
  - If the number is <1 exp is negative $0.0000017 \rightarrow 1.7 \times 10^{-6}$

Scientific Notation Examples

Write the Following in Scientific Notation:

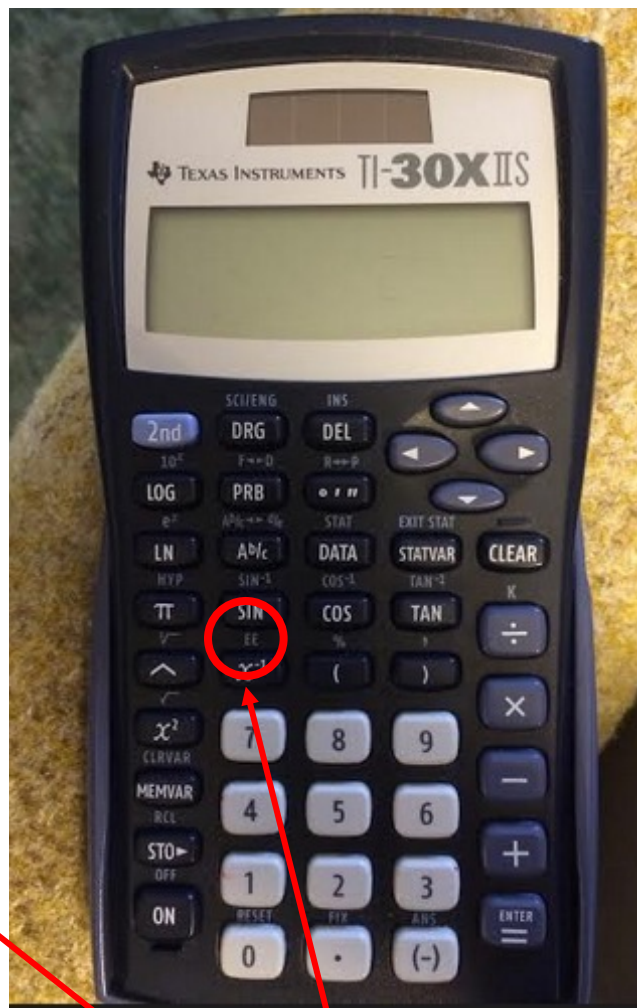1.) 280000000

2.) 280.0

3.) 0.000000004577

4.) 0.00000060

Write the Following in Standard Format:

1.) 2.45×10^2

2.) 3.98×10^6
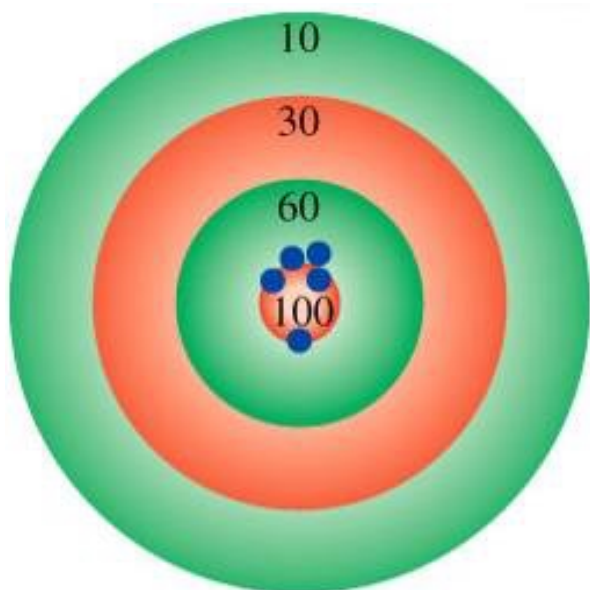
3.) 4.29×10^{-3}

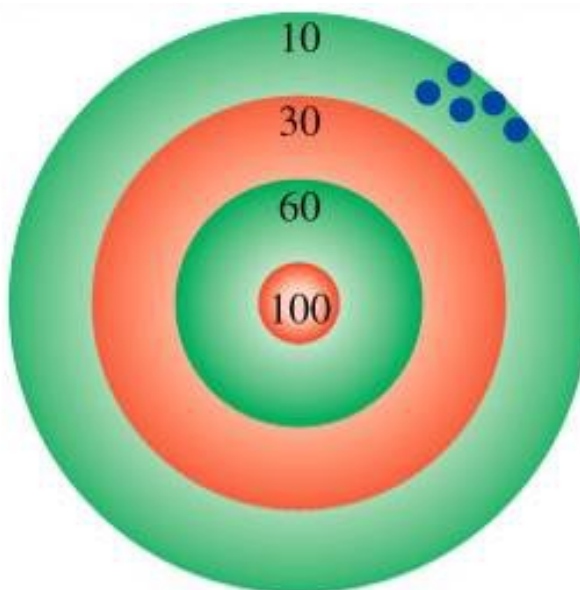4.) 8.0×10^{-6}

Use EXP, SCI, EE or x10^x keys on calculator

Precision and Accuracy

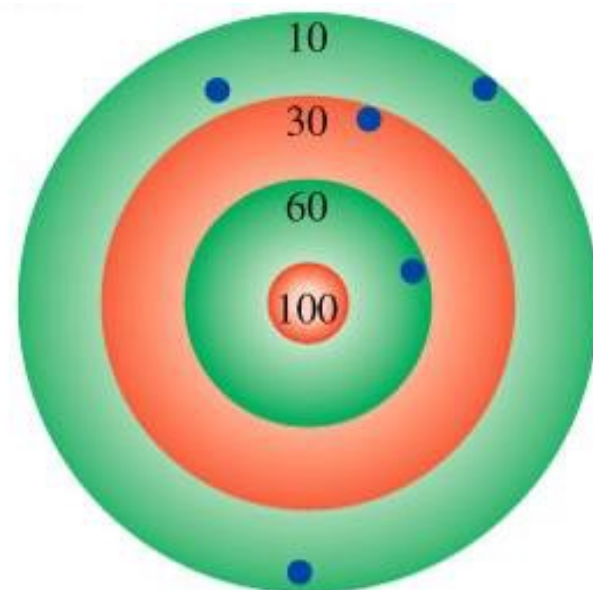**Accuracy** – how close a measurement is to the true value
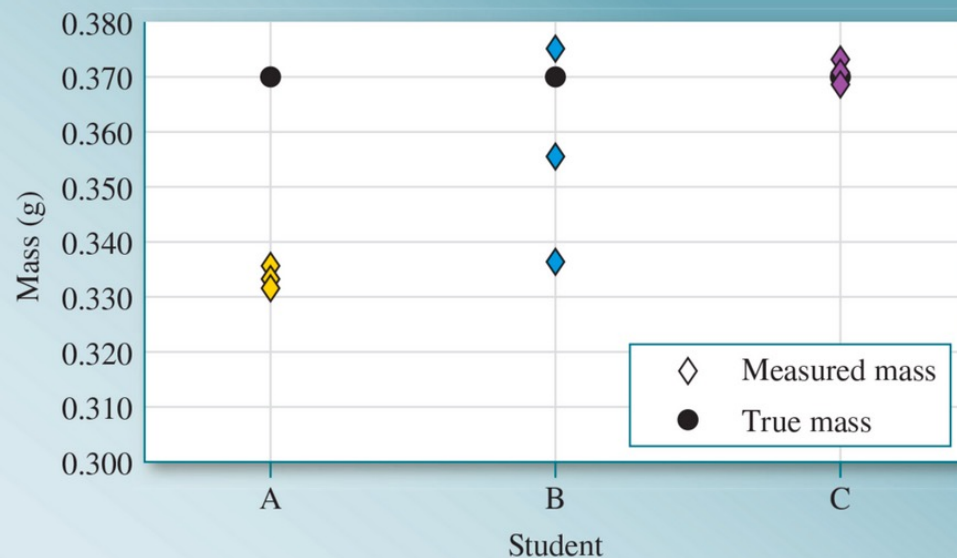**Precision** – how close measurements are to each other

accurate
&
precise

precise
but
not accurate

not accurate
&
not precise

Precision and Accuracy

	Student A	Student B	Student C
Measurement 1	0.335 g	0.357 g	0.369 g
Measurement 2	0.331 g	0.375 g	0.373 g
Measurement 3	0.333 g	0.338 g	0.371 g

Percent Error

Comparison of experimental results to expected or real values

- Usually reported <u>without</u> a + or - sign

$$\% \text{ error} = \frac{|\textbf{Experimental value} - \textbf{Real value}|}{\textbf{Real value}} \times 100$$

Experimental value - Real value = **Deviation**
- Often reported with a + or – sign

Real value:
- Widely accepted, often an industry standard value
- Average of several experiments can sometimes be used if real value is unknown

Dimensional Analysis
Problem Solving & Canceling Units

Look at question:

How many kilograms of methanol will fill a 15.5 gallon fuel tank of a car modified to run on methanol? (Density of methanol = 0.791 g/mL)

What unit do you want to solve for? kilograms (kg)
What information do you need?

Data in problem: Volume = 15.5 gallons
Density of methanol= 0.791 g / mL

Data to look up: Gallon to Liter conversion: 1gal= 3.785L

Data to know: 1000mL = 1L & 1000g = 1kg

$$\frac{kg}{1} = \frac{0.791g}{1ml} \, x \, \frac{1kg}{1000g} \, x \, \frac{1000mL}{L} \, x \, \frac{3.785L}{1gal} \, x \, \frac{15.5gal}{1} = 46.4kg$$

Dimensional Analysis Problems

1) How many kilograms of methanol will fill a 15.5 gallon fuel tank of a car modified to run on methanol? (Density of methanol = 0.791 g/mL; 1 gal = 3.785 L) A: 46.4 kg

2) How many liters are equal to 500. cm^3? A: 0.500 L

3) A cube with sides measuring 7.50 m has a mass of 0.04567 mg. What is the density of the cube in μg/mL? A: 1.08 x 10^{-7} μg/mL

Temperature Units: Celsius & Kelvin

- Kelvin is the official SI unit but degrees Celsius are often used.
- 0K is absolute zero – lowest possible temp.
  - Never actually reached – will not have 0K
- Temp in Kelvin = °C + 273.15
- Temp in °C = Kelvin – 273.15
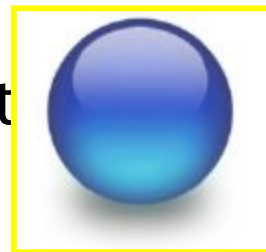- Fahrenheit – rarely used in science today

Classifications of Matter

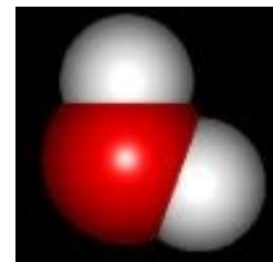What is in the material you are investigating?

Pure materials

<u>Atom</u>:
- Smallest distinctive unit w/ properties of element
- Ions are charged atoms
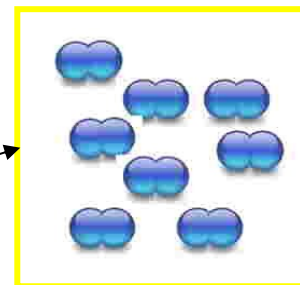
<u>Molecule</u>:
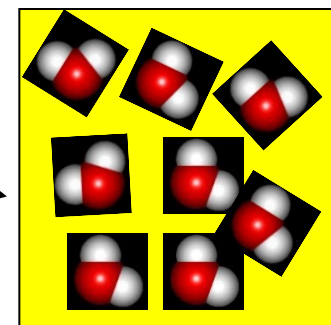- 2 or more atoms together

<u>Pure Substance:</u>
- specific composition & distinct properties
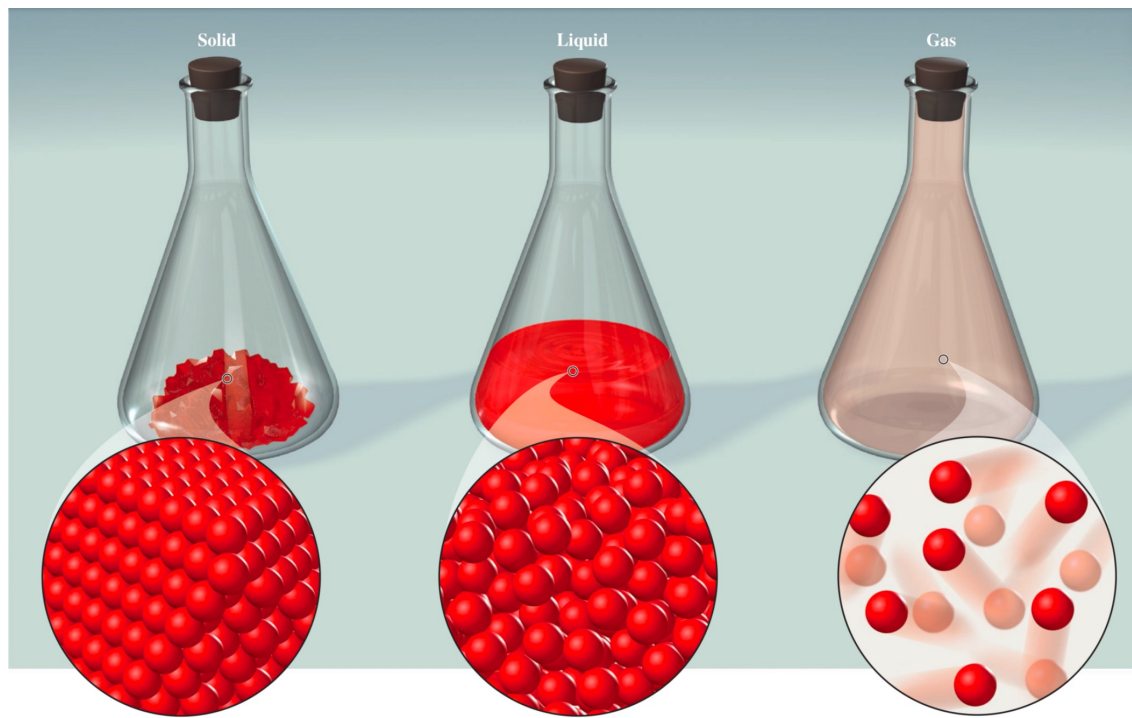- **TWO** types of pure substances:

  – **Element** → one type of atom

  – **Compound** → more than one type
  of atom <u>chemically bonded</u>

  - Compounds contain more than
  one element – still a pure substance!!!

States (Phases) of Matter

Solid   Liquid   Gas

Solid:
- Particles close together
- Orderly arrangement
- Little freedom of motion
- Specific shape & volume

Liquid:
- Particles free to move around each other
- Specific volume
- No specific shape

Gas:
- Particles very far apart
- Particles free to move around
- No specific shape or volume

Liquids & gases are fluids – they can "flow"

Mixtures

Mixture: Combination of 2 or more pure substances
- Can be separated by physical means

Homogeneous Mixture

- Substances stay mixed
- No distinct layers
- Uniform properties
- **Also called a "solution"**

14 karat gold
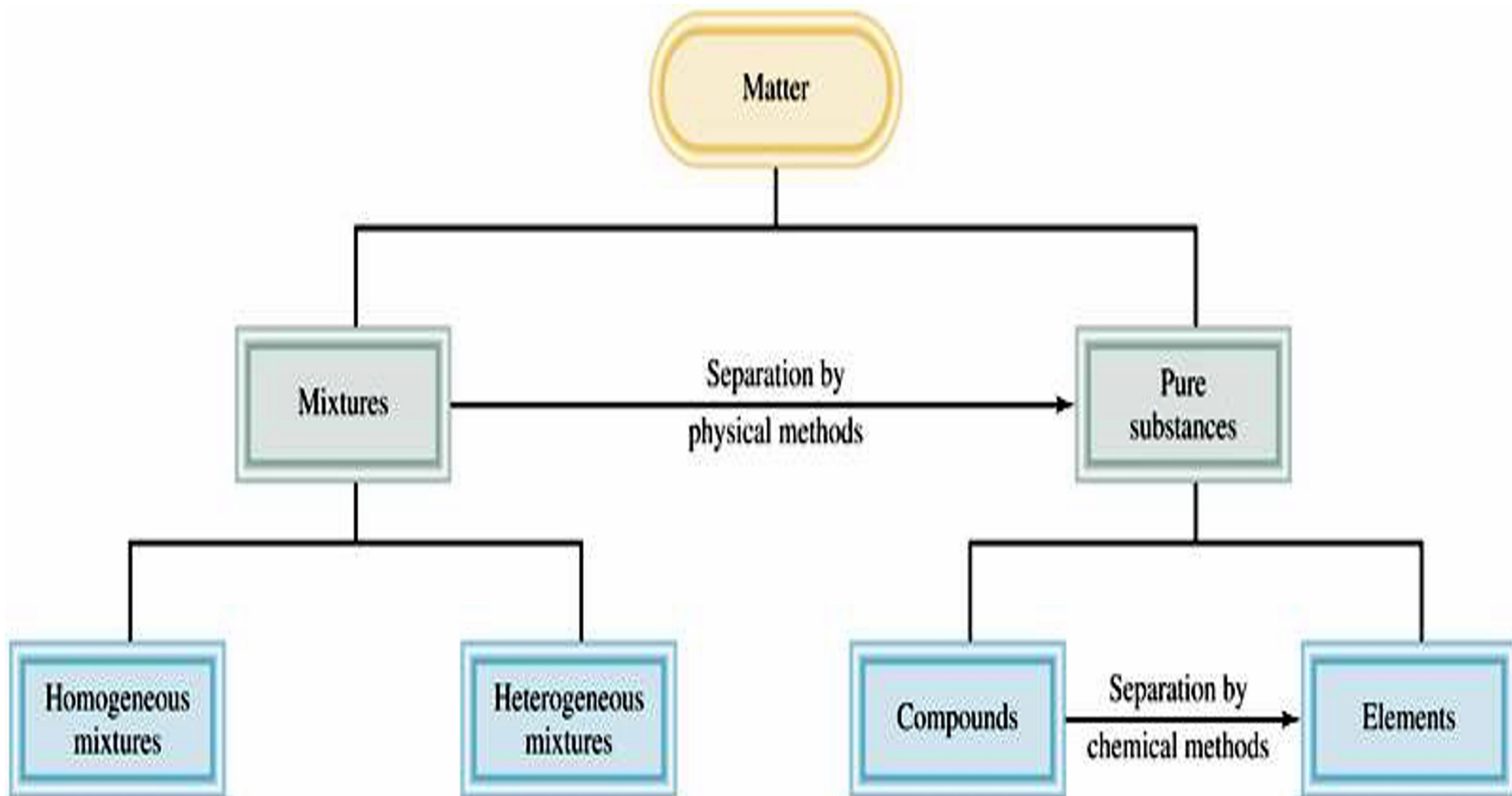Mixture of gold and silver

Heterogeneous Mixture

- Substances separate easily
- Distinct layers often seen
- Properties may not be uniform

Iron filings and sand

Matter Summary

	Heterogeneous mixture	Homogeneous mixture	Pure Substance
	😃		
			😃 element
			😃 compound
			😃 compound
		😃 solution	
			😃 compound

Physical and Chemical Properties of Matter

Can be used to identify & separate substances

port-magazine.com

Physical Properties of Matter

Can be changed without changing molecular composition

Chemical identity is NOT CHANGED
eg: smashing a window – still glass
melting ice – still water

Phase changes are physical changes
(solid to liquid to gas etc.)
Melting, freezing, boiling, etc.

CHEMICAL BONDS ARE NOT BROKEN DURING PHASE CHANGES!

Can be used to ID a substance without damage
Color, odor, solubility, conductivity, density
molecular mass, boiling/melting points
Original compound can be recovered

Chemical Properties of Matter

Describe how chemicals react with each other

What will they react with?
How will they react?

- Generate heat or light?
- Burn? Explode?
- Decompose slowly? (Rusting, rotting)

Ready.gov

Compositional changes to molecules

- Often called a chemical change
- Original material changed on an atomic level

Original compound no longer present

- Compound cannot be restored to its original form without another chemical change

Extensive and Intensive Properties

<u>Extensive Property</u>: Depends on amount of matter present

> ex: mass, length, volume, heat, <u>intensity</u> of color or odor

<u>Intensive Property</u>: Independent of amount of matter present

> ex: Temperature, boiling point, color, odor

> Often a calculated ratio
> > ex: Density (mass/vol ratio)
> > Molar mass (grams/mol)
> > Specific heat (J/g)

Intensive properties can be used to identify a material, extensive properties cannot. Why?