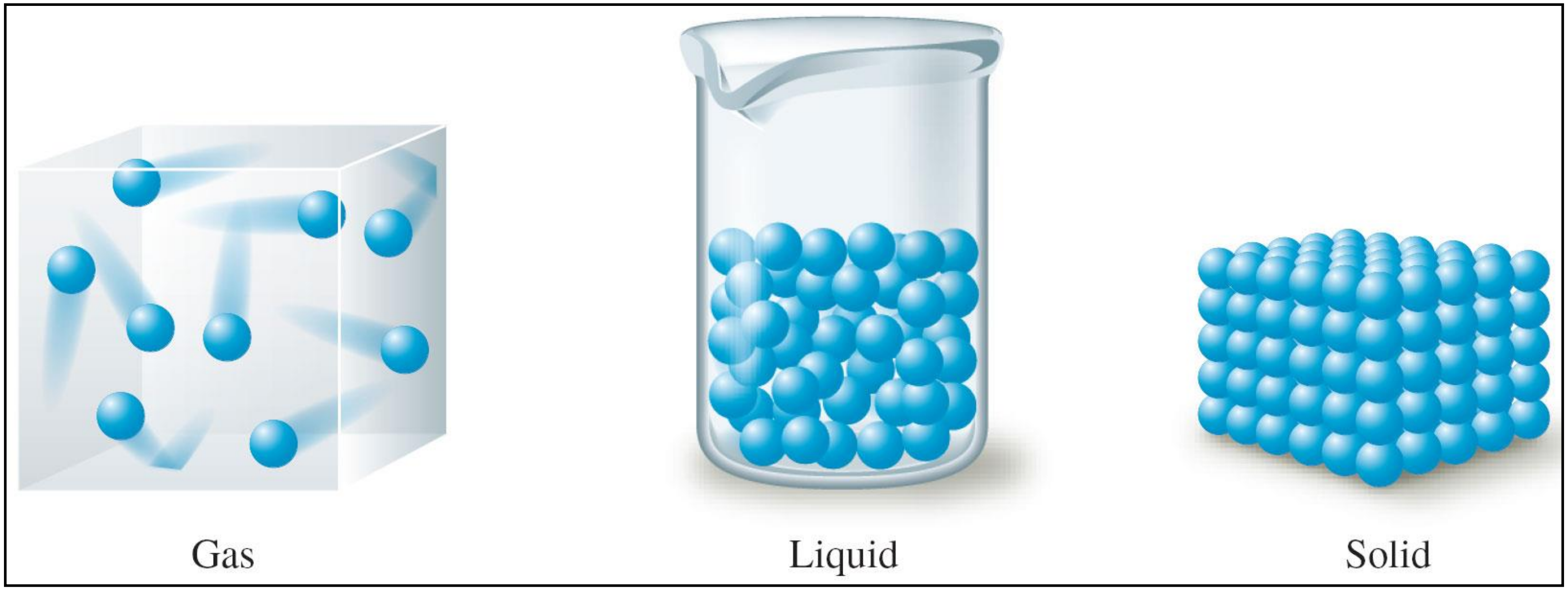
Lecture 2 Goals

- Slides covering McMurry Ch 1.2 – 1.10
  - Lots of background info you will use all semester!
  - This material will prepare you for Homework #1, due next Saturday
- The short list of (potential exam) topics to know:
  - 1.1* Physical vs. chemical change (see also 1.6*)
  - 1.2 Describe the states of matter (solid, liquid, gas) at the atomic scale
  - 1.3 Pure vs. mixture, homogeneous vs. heterogeneous, element vs. compound
  - 1.4 Memorize first 30 elements & symbols, plus Br, I, Ag, Au, Hg, Pb, Ba, Cd, Sn
  - 1.5 Find metals, nonmetals, and metalloids on the periodic table
  - 1.6* Understand the terms: (chemical) reaction, reactants, and products
  - 1.7 Know your standard units (g, cm, °C, etc.) and Metric prefixes (nano-kilo)
  - 1.8 Know the meaning of mass/weight, length, and volume
  - 1.9 Know how to count significant figures (sig figs or s.f.), especially whether or not to count any zeros. There is always one uncertain digit at the end.
  - 1.10* Practice scientific notation until you are good at it!!!

* You may need to self study Ch 1.1, 1.6, and 1.10, if we run out of time in lecture.

1.2 States of Matter



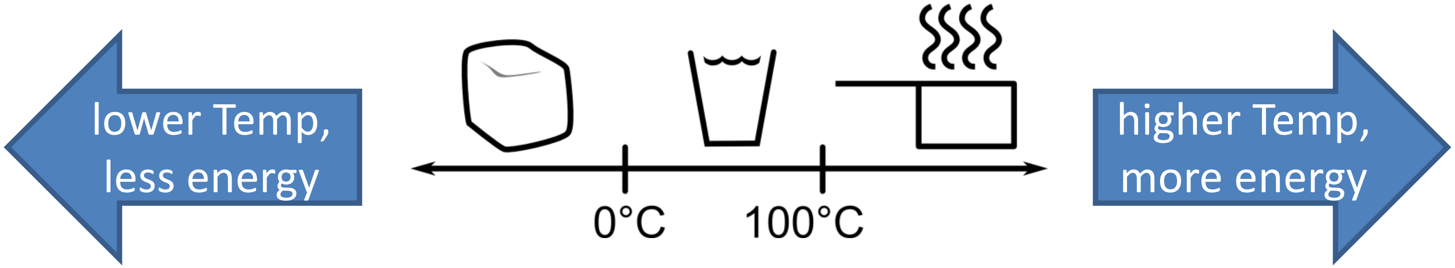
The state of matter is typically gas (g), liquid (l), or solid (s).

A change of state is always a physical change…
…because the chemical identify of the matter is not altered.

Example: Steam (g), water (l), and ice (s) are the same chemical species (H_2O) at different states. Each blue dot represents a water “molecule,” the smallest indivisible unit of water.

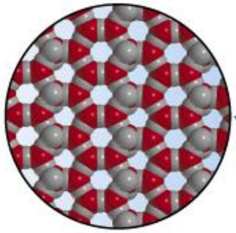
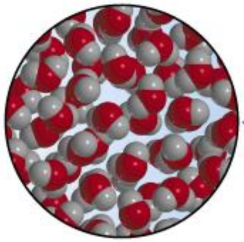
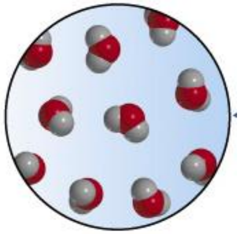
Why do different states exist?

- Temperature is the common explanation
  - Below its freezing point (f.p.), a substance is a solid
  - Above its boiling point (b.p.), a substance is a gas
  - Between the f.p. and b.p., a substance is liquid

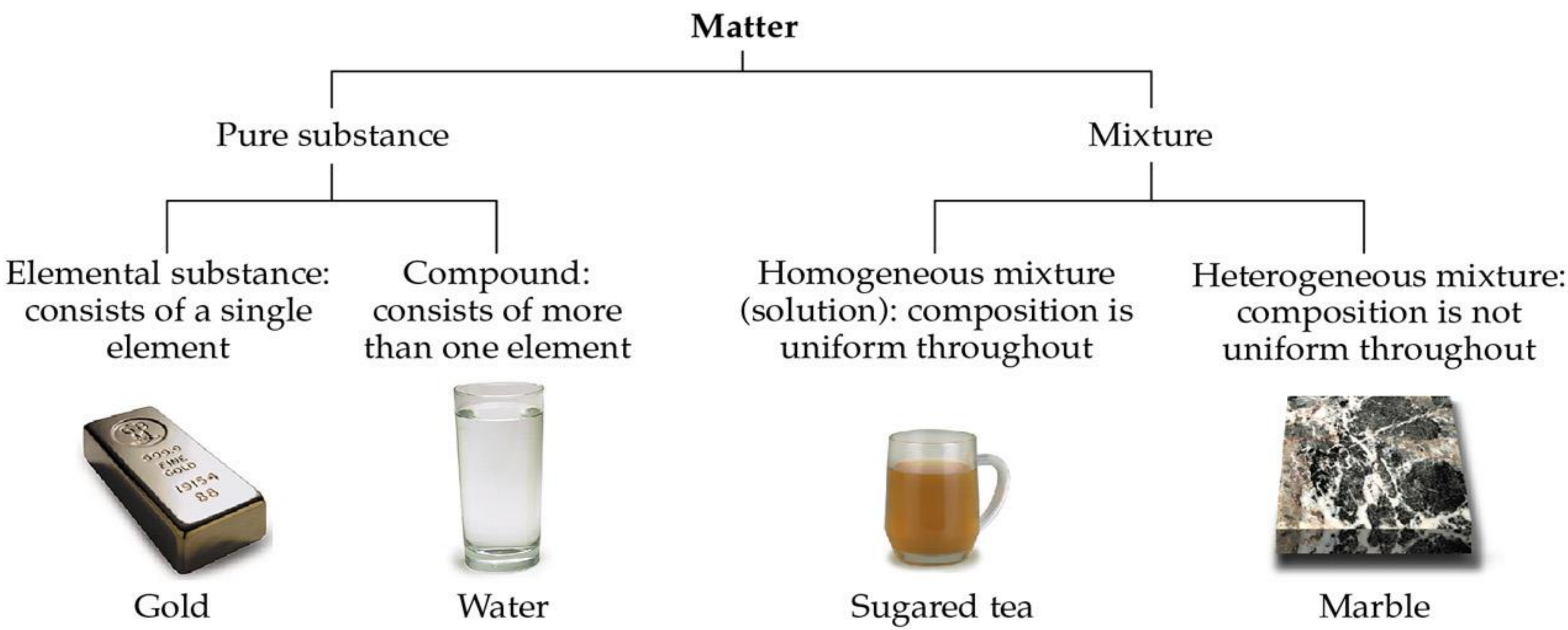


- In chemistry, temperature is a measure of <u>energy</u>
  - Higher Temp means more molecular kinetic (motion & vibration) energy
    - Solid molecules have the lowest energy and the least motion
      - Molecules are fixed in place and only vibrate
    - Liquid molecules have intermediate levels of energy and motion
      - Molecules move freely around each other (and also vibrate)
    - Gas molecules have the highest energy and the most motion
      - They fly about freely at high speed (and also vibrate)

Microscopic vs Macroscopic characteristics

	Microscopic The atoms/molecules are…	They look like:	Macroscopic The bulk materials is…
solid	…touching and fixed into a rigid lattice (array).		…rigid, and has surfaces
liquid	…touching yet free to move about… No lattice.		… fluid (not rigid) to take shape of the container, and has a surface
gas	…flying around with large distances in between.		…fluid to completely fill container, without any surface.

1.3 Classification of Matter



Note that mixing is always a physical change.

Transformations among elements and compounds are chemical changes.

But what is an element???

If it's an element, it's on the periodic table.

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

Elements are listed on the periodic table. Compounds contain multiple elements.

Example: Hydrogen (H) and oxygen (O) are elements. Water is a compound with formula H_2O, representing a molecule with two hydrogen atoms and one oxygen atom.

Homo- (same) and *Hetero-* (different)

- Homogenous – same composition throughout
  - “well mixed” at the molecular level
  - Visibly uniform at the macroscopic level
  - Examples:
    - sugar dissolved in water
    - air (a mixture of pure oxygen, nitrogen, argon, etc.)
    - brass is an alloy (metal mixture) of elements copper and zinc

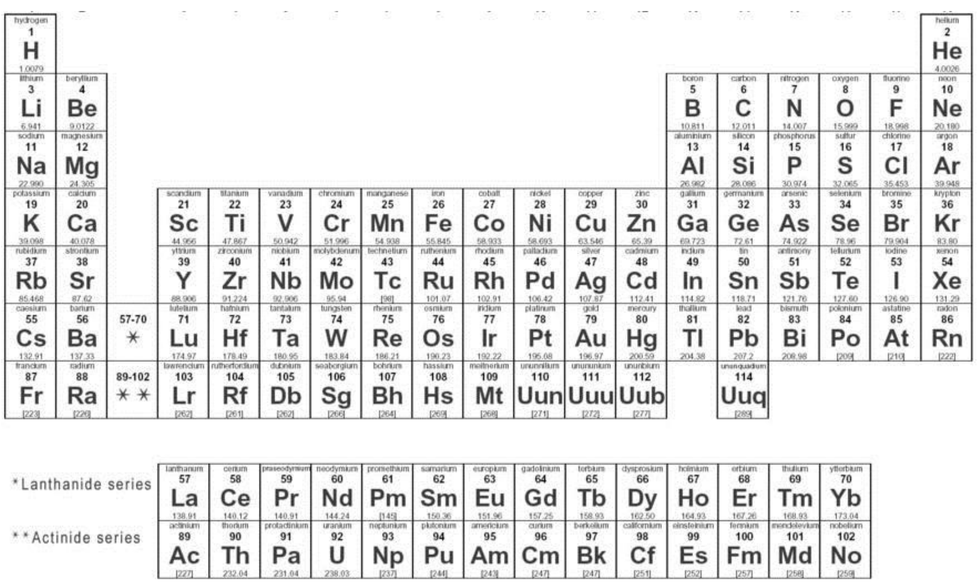
sugar water

- Heterogeneous – different/variable composition
  - “chunky” with patches of different composition
  - could pick apart into pure substances by hand
  - Examples:
    - sand stirred into water
    - soil

“sand water”

1.4 Elements and Symbols

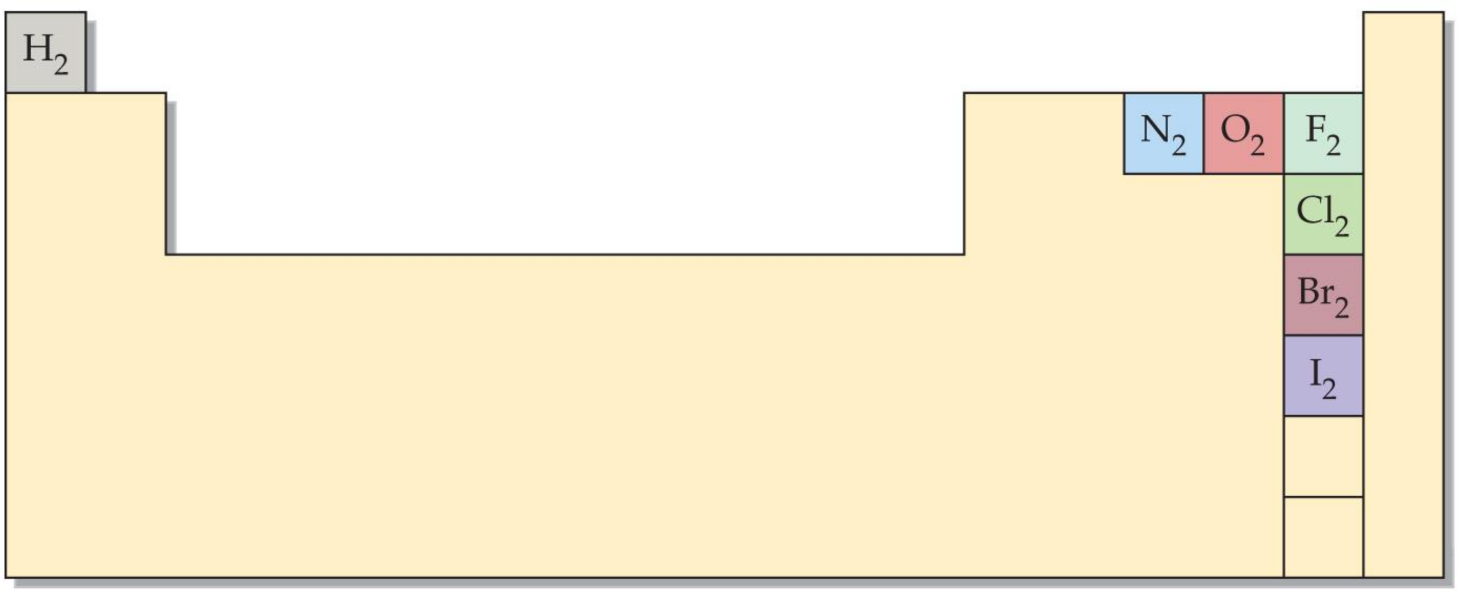
- Each element has a unique symbol
  - 1 or 2 letters
    - First letter capitalized
    - Second letter lower case (if present)
- Some element symbols are derived from Latin
    - Au = gold for Latin “aurum” for aura or glow
    - Pb = lead from Latin “plumbum” used for (water) pipes



Things to Know

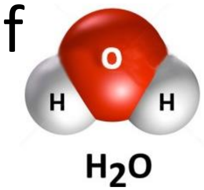
- Names of first 30 elements
  - plus Br, I, Ag, Au, Hg, Pb, Ba, Cd, Sn

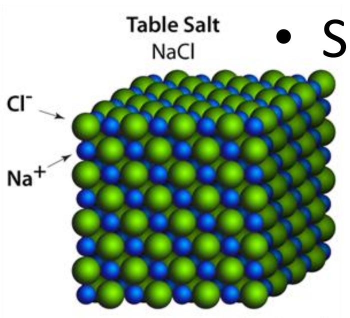
- Which elements are <u>diatomic molecules</u>
  - Technically, the diatomics are <u>not</u> compounds
  - Recall that compounds have multiple elements

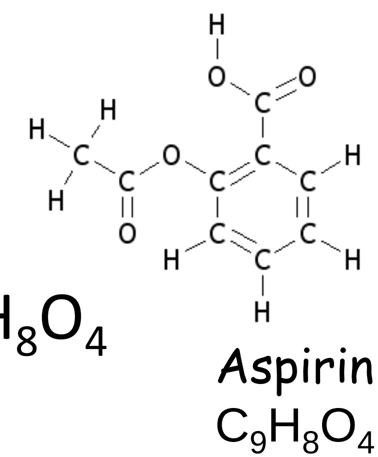


Chemical Formulas and Compounds

- Compound – substance composed of multiple elements
  - Compounds always have the same proportions of elements
    - Water (formula H_2O) is always two H per one O
    - Sodium chloride (NaCl, table salt) is always one Na per one Cl





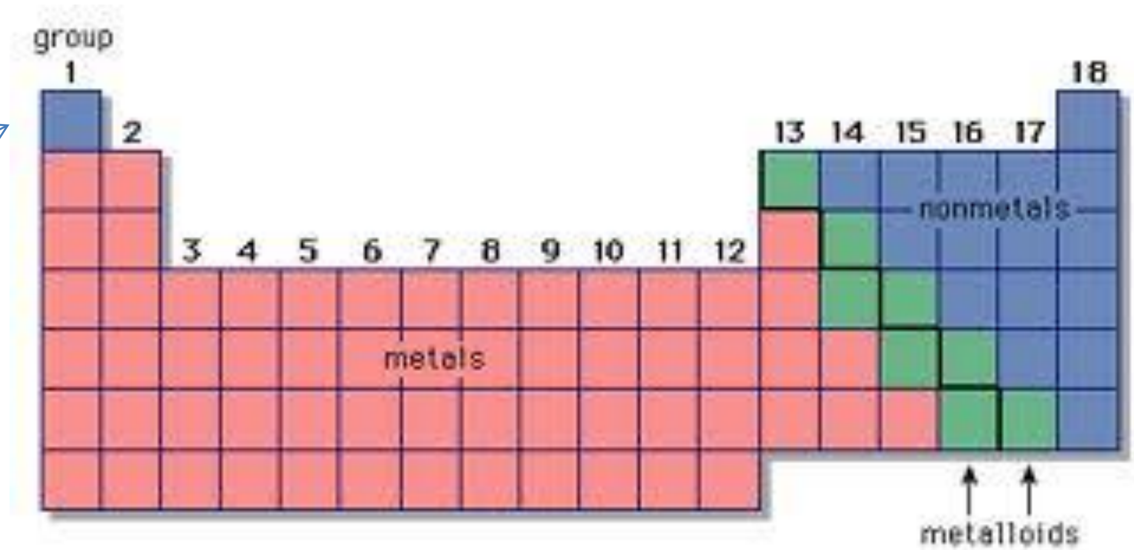


  - "Big" compounds exist such as aspirin $C_9H_8O_4$
- Pure elements – just a single element
  - Mercury has the "formula" Hg

1.5 Elements and the Periodic Table

- Elements are roughly divided into 3 groups:
  - **Metals:** Found on the left side of the table
  - **Nonmetals:** Found on the right side of the table
  - **Metalloids:** Found along a diagonal trail between metals and nonmetals

Hydrogen is unique… it doesn't quite fit because the first row only has 2 elements.



Metals

- Most of the elements (94 of 118), left side of periodic table

- Solid at room temperature (except mercury, Hg)
- Conduct heat and electricity
- Lustrous (shiny)
- Malleable (bendable) and ductile

(a) (b) (c)

Nonmetals

- Only 18 elements, right side of periodic table
- Tend to be gasses at room temperature
  - 11 gasses, 6 solids, 1 liquid
  - Insulators – poorly conduct heat and electricity
  - Brittle (easily cracked) when solid

liquid nitrogen evaporating into gas

(a)

sulfur – solid powder

(b)

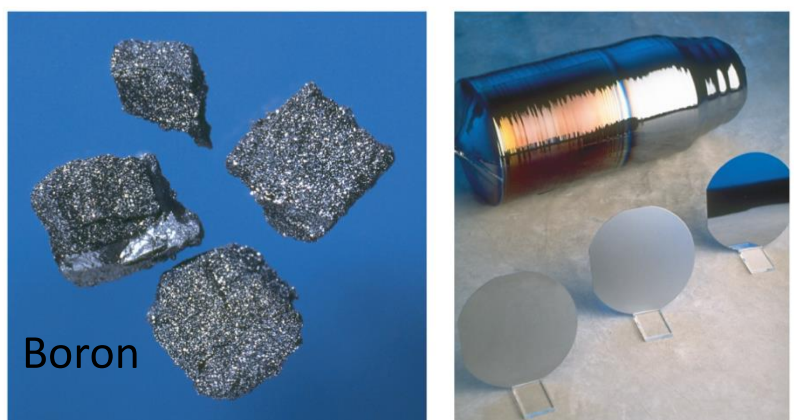
iodine crystals

(c)

chlorine gas

Metalloids

- 6 to 8 elements, depending on who's counting
- Properties intermediate of metals and nonmetals
- Semiconductor properties are important
  - Conductor/insulator properties change with applied voltage
  - Important for the electronics/hardware and emerging nanotechnology industries



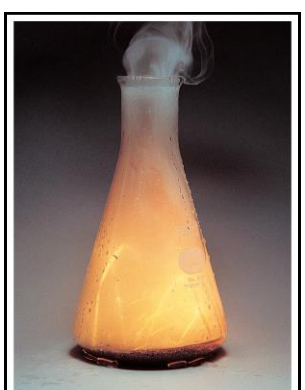
(a) (b)

silicon – manufactured as a thin "wafer"

1.6 Chemical Changes *[study at home]*

How do we know when a chemical (as opposed to physical) change has occurred?

A chemical change has occurred when the chemical composition of matter has changed… but you generally can't "see" the molecules!



You must infer when a chemical change has occurred.

Heat, light, and/or electricity are generally absorbed or emitted when a chemical reaction occurs.

Chemical change examples

New (-ish) pliers made of iron (Fe)

chemical change

Very old pliers have been oxidized to iron oxide (Fe_2O_3), or rust.

Potassium (K) and water (H_2O)

chemical change

Potassium reacting with water, to produce a flame, indicating a reaction is occurring.

Dramatic change of properties

- Two deadly chemicals, sodium (Na) and chlorine (Cl), react violently to form edible table salt (NaCl)
- Properties can change dramatically upon reactions

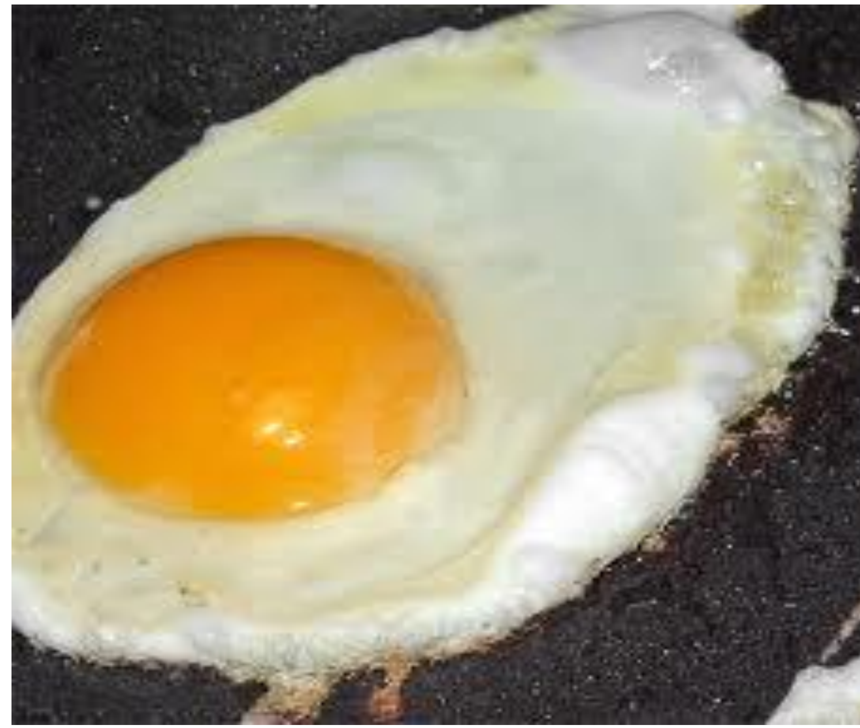
$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

Other signs of chemical reaction

Nickel (Ni), a solid metal, is mixed with a colorless solution of hydrochloric acid (HCl) in a test tube

- Change in color
- Solid dissolves
- Gas bubbles appear

A chemical or physical change?



1.7 Physical Quantities

- Physical quantities are physical properties that can be measured on a number scale
- They <u>always</u> have 2 parts:
  - A number …
  - … followed by its units.*

*It's minus one point every time you forget the units on an exam. Please don't do this!

The Metric System*

- There are base units and prefixes
  - base units indicate the type of property: length, mass, temperature, etc.
    - SI and metric base units are similar
  - prefixes form units that differ by powers of ten

TABLE 2.1 Some SI and Metric Units and Their Equivalents

QUANTITY	SI UNIT (SYMBOL)	METRIC UNIT (SYMBOL)	EQUIVALENTS
Mass	Kilogram (kg)	Gram (g)	1 kg = 1000 g = 2.205 lb
Length	Meter (m)	Meter (m)	1 m = 3.280 ft
Volume	Cubic meter (m^3)	Liter (L)	1 m^3 = 1000 L = 264.2 gal
Temperature	Kelvin (K)	Celsius degree (°C)	See Section 2.9
Time	Second (s)	Second (s)	—

*There is no such thing as "English units" in chemistry. Most science agrees.

Other units are "derived" from the base units

Derived Units

Quantity	Definition of Quantity	SI Unit
Area	Length squared	m^2
Volume	Length cubed	m^3
Density	Mass per unit volume	kg/m^3
Speed	Distance traveled per unit time	m/s
Acceleration	Speed changed per unit time	m/s^2
Force	Mass times acceleration of object	$kg \cdot m/s^2$ (= newton, N)
Pressure	Force per unit area	$kg/(m \cdot s^2)$ (= pascal, Pa)
Energy	Force times distance traveled	$kg \cdot m^2/s^2$ (= joule, J)

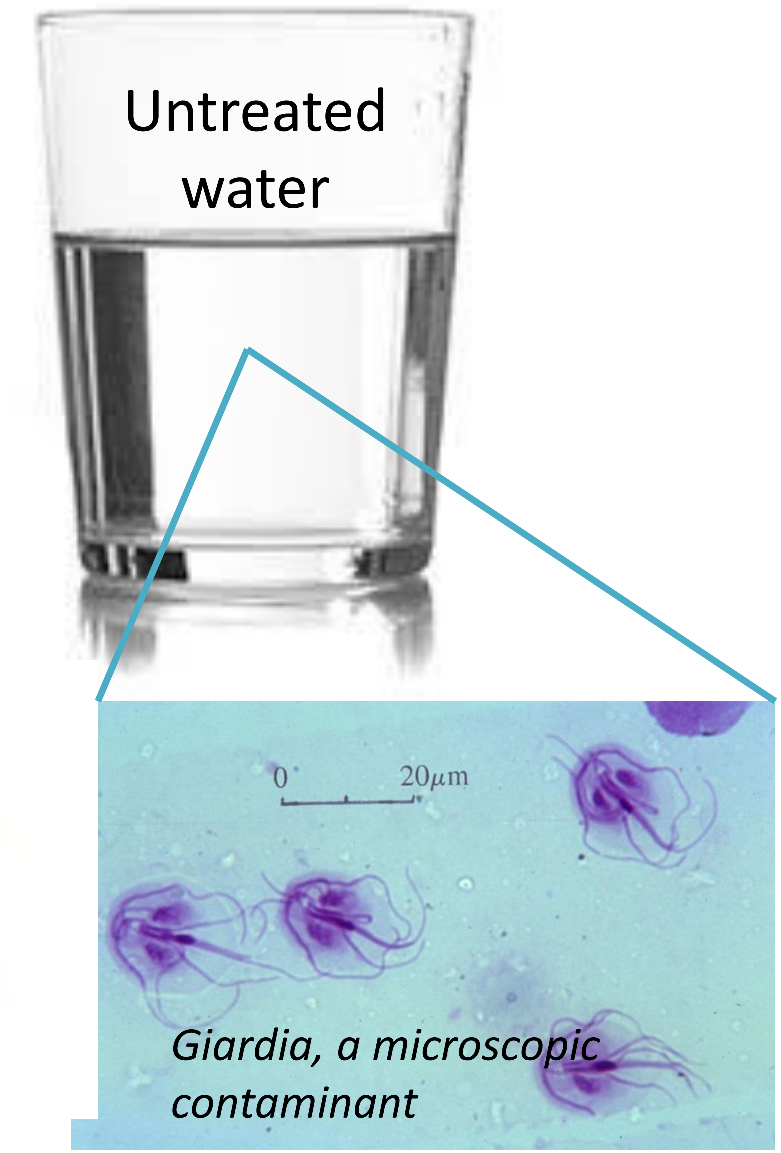
Know the prefixes in blue (nano- to mega-)

Table 1.2 ▶ The Prefixes Used in the SI System (Those most commonly encountered are shown in blue.)

Prefix	Symbol	Meaning	Exponential Notation*
exa	E	1,000,000,000,000,000,000	10^{18}
peta	P	1,000,000,000,000,000	10^{15}
tera	T	1,000,000,000,000	10^{12}
giga	G	1,000,000,000	10^{9}
mega	M	1,000,000	10^{6}
kilo	k	1,000	10^{3}
hecto	h	100	10^{2}
deka	da	10	10^{1}
—	—	1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000001	10^{-6}
nano	n	0.000000001	10^{-9}
pico	p	0.000000000001	10^{-12}
femto	f	0.000000000000001	10^{-15}
atto	a	0.000000000000000001	10^{-18}

Let's take a 5-minute break.

Pop quiz: Which glass of water to drink?



The glasses appear the same at the macro scale, and yet they are very different at the microscale.

What is smaller than microscale?

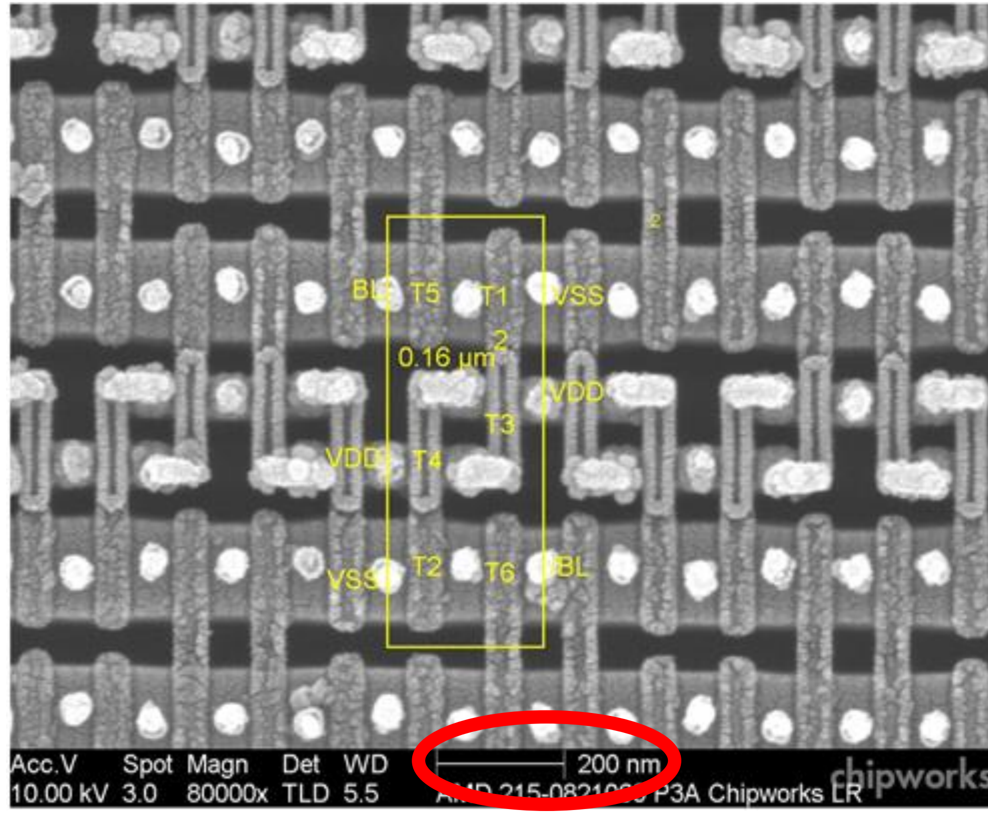
Table 1.2 ▶ The Prefixes Used in the SI System (Those most commonly encountered are shown in blue.)

Prefix	Symbol	Meaning	Exponential Notation*
exa	E	1,000,000,000,000,000,000	10^{18}
peta	P	1,000,000,000,000,000	10^{15}
tera	T	1,000,000,000,000	10^{12}
giga	G	1,000,000,000	10^{9}
mega	M	1,000,000	10^{6}
kilo	k	1,000	10^{3}
hecto	h	100	10^{2}
deka	da	10	10^{1}
—	—	1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000001	10^{-6}
nano	n	0.000000001	10^{-9}
pico	p	0.000000000001	10^{-12}
femto	f	0.000000000000001	10^{-15}
atto	a	0.000000000000000001	10^{-18}

Can you visualize a billionth?

Millions or even billions of "devices" in a small computer chip is common.

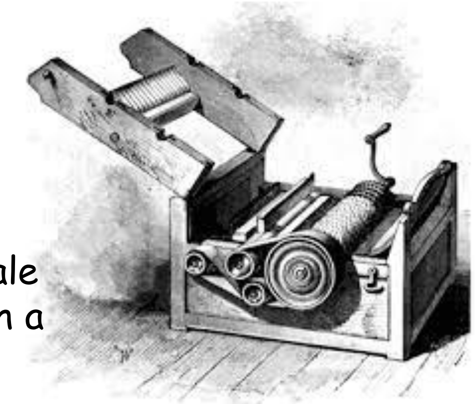
What do these devices look like?



An electron microscope shows individual devices, measured in nanometers.

Can you think of other things measured in billions/billionths?

A brief history of the smaller and smaller (Not on any exam.)



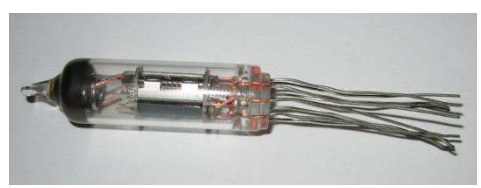
A human-scale machine with a hand crank

- Millimeter sized, interchangeable gears
  - Eli Whitney's cotton gin in 1793

- Micrometer tolerances & computer aided design (CAD)
  - Toyota's continuous improvement (kaizen) over the 20th Century

- But this is not small enough for digital computing!

A digital adding machine made of vacuum tubes.

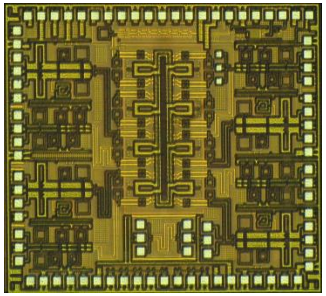


hearing aid vacuum tube 35x10 mm machined to micrometer tolerances.

Solid state technology (not on exam)

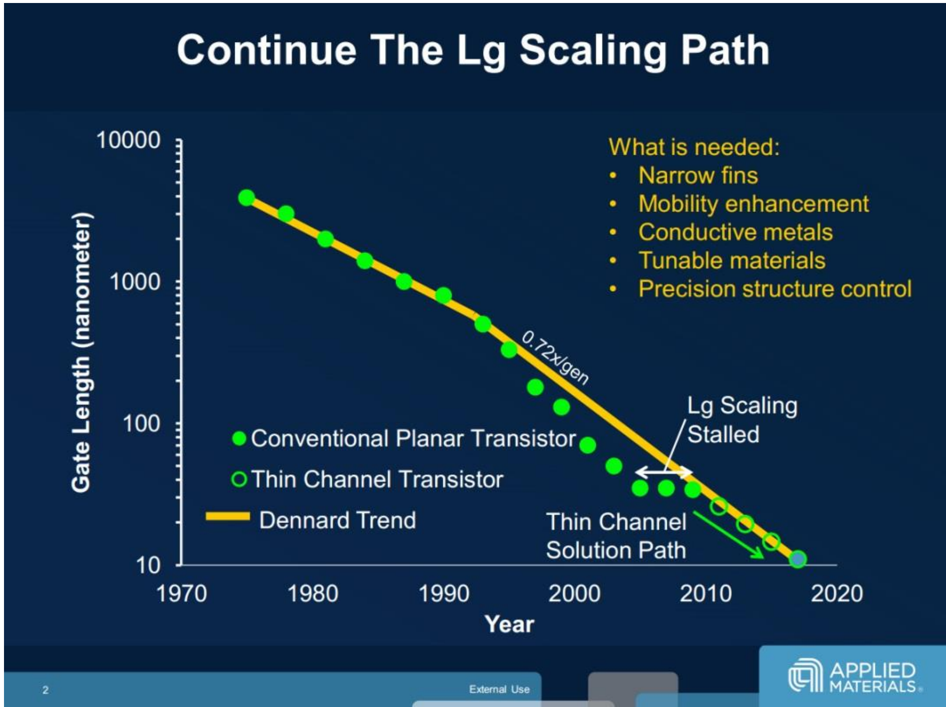
- Transistor invented 1947
  - Layers of solid materials (semiconductors) with novel electrical properties
  - No moving parts – chemical synthesis/etching

two 1970s radio transistors

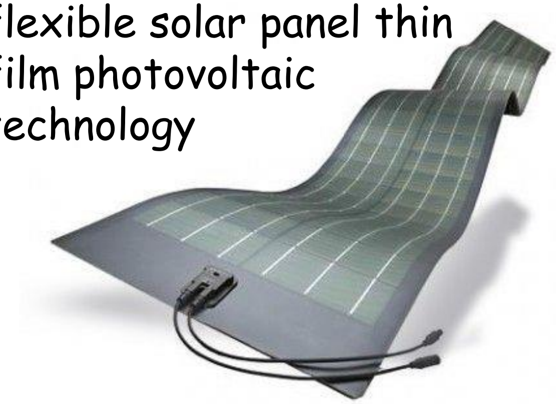


modern integrated circuit (IC) with billions of transistors

- Manufactured at exponentially decreasing scale over time
  - 1970s ~3 **micro**meter gate length
  - 2020 10 **nano**meter gate length

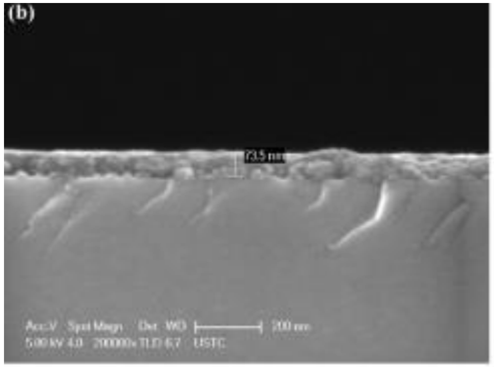


nano everywhere!

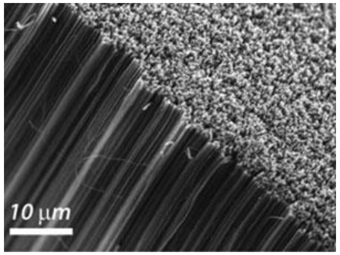


flexible solar panel thin film photovoltaic technology

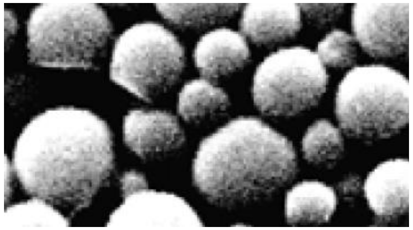
nano-crystal studded glass changes color to filter light



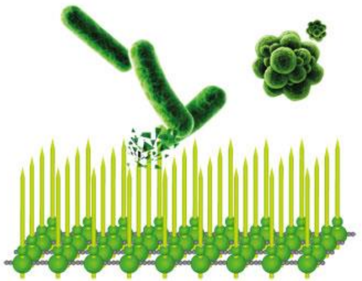
SEM image of 300 nm VO_2 thin film on silicon water. It could generate electricity instead of dissipating heat.



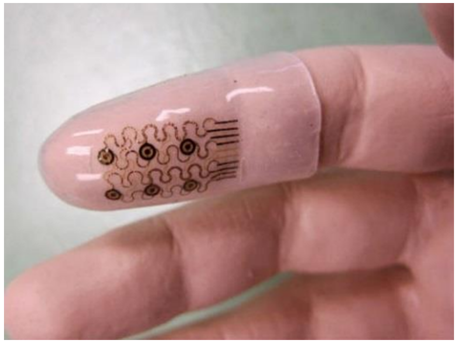
Carbon nanotubes are 100x stronger than steel!



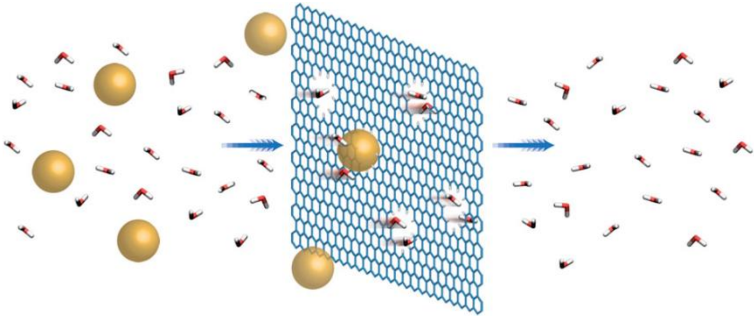
nanospheres for drug delivery



“nano-swords” for antimicrobial protection… on my sneakers!



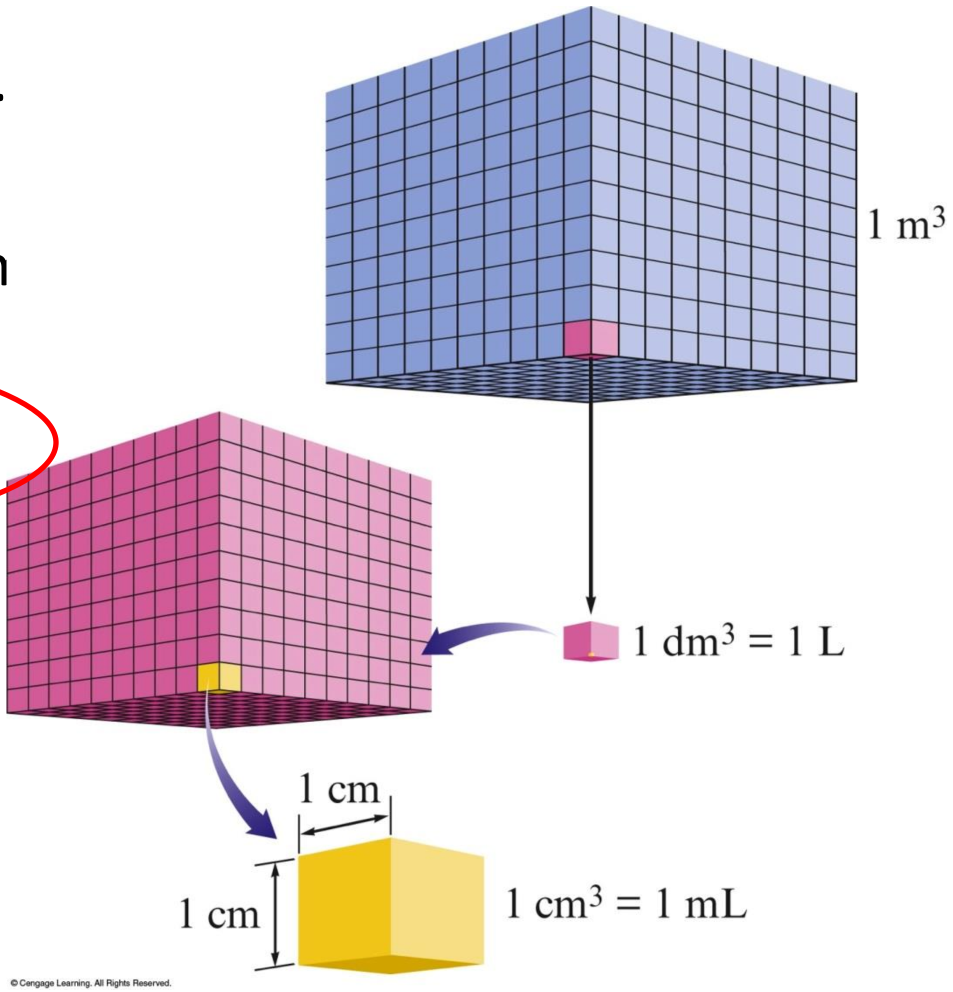
Smart fingertip electronics



graphene, a single layer of carbon, acts as a water filter

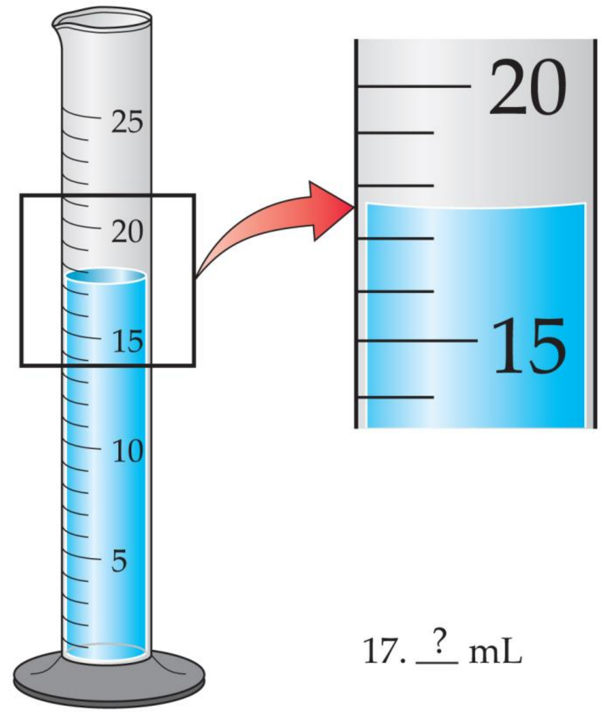
1.8 Volume is “derived” from length

- Measure of the amount of 3-D space occupied by a substance.
- SI unit = cubic meter (m^3)
- Commonly measure solid volun in cm^3.
- 1 mL = 1 cm^3 or 1 cc (cubic cm)



1.9 Measurement uncertainty (sig figs)

- Chemists follow a convention when making any measurement
  - State all known digits from the measurement device
  - Then <u>guess</u> the very last digit

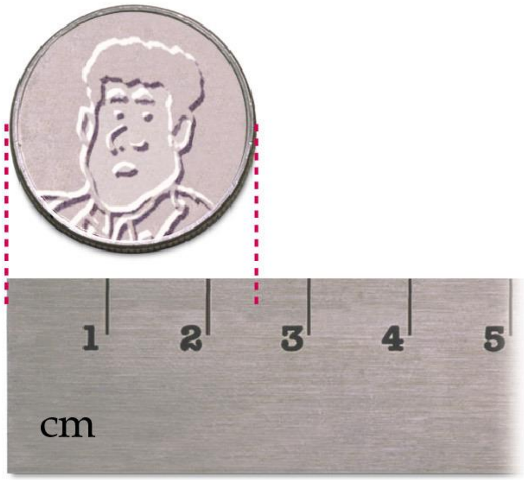


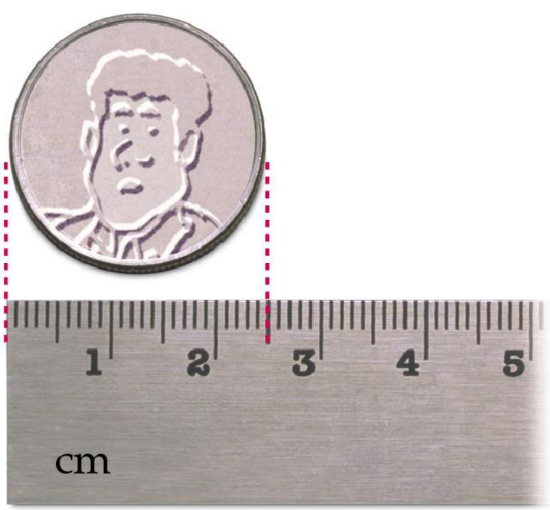
Step 1. Each horizontal line indicates 1 mL.

Step 2: The liquid level is clearly above 17 mL and clearly below 18 mL.

Step 3. Guess the last digit. It's about half way between 17 and 18 mL, so a good guess would be 17.5 mL. Other readings such as 17.6 mL or 17.4 mL would also be acceptable.

Step 4: The measurement has 3 <u>significant figures</u>, and the last is implied to be a guess.





- How many sig figs on top?

- How many sig figs on bottom?

Why do we use sig figs???

- Below are two measurements of the mass of the <u>same object</u> from <u>two different balances</u>
- The *same* quantity is being *described* at two different levels of precision

Uncertain digit

54.07 g A mass between 54.06 g and 54.08 g (±0.01 g)

Uncertain digit

54.071 38 g A mass between 54.071 37 g and 54.071 39 g (±0.000 01 g)

The chemist measuring 54.07138 g (7 sig figs) has a more precise (and thus more costly) instrument than the one reporting only 4 sig figs.

You can "read between the lines" of a lab report to understand the precision of the equipment used for the measurements. This helps the reader understand the uncertainty (amount of potential error) in the results.

Counting sig figs I

- Nonzero integers are always **significant** figures
  - 3456 has 4 sig figs
  - 3456.789 has 7 sig figs

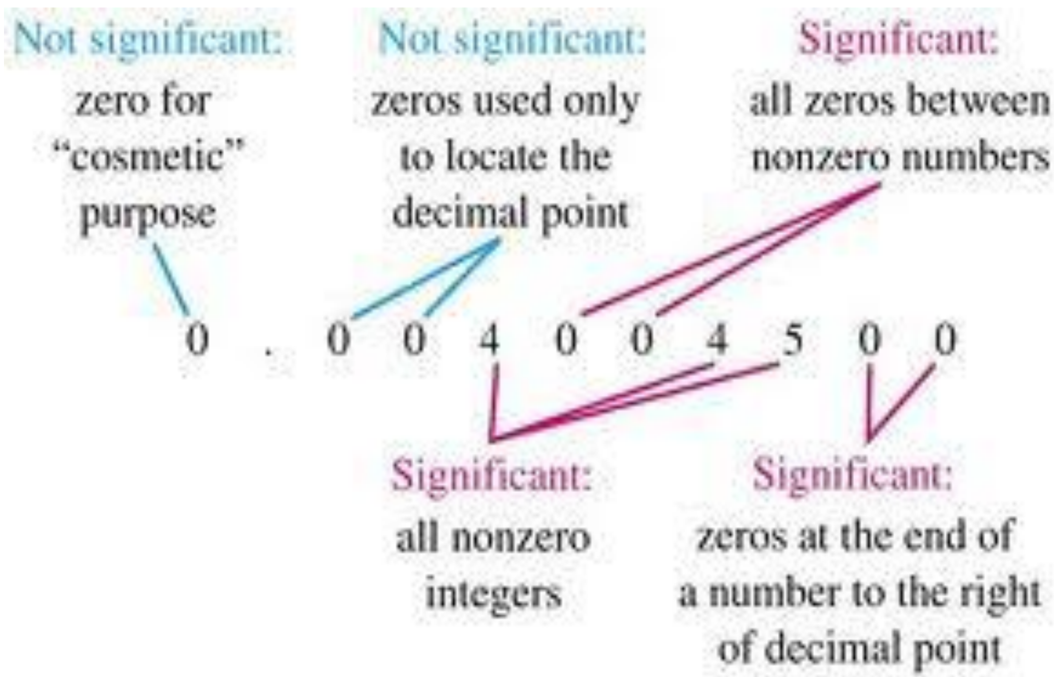
- Zeros in the middle ("captive zeros") are significant, just like any digit
  - 3406, 3006, and 3056 all have 4 sig figs
  - 3056.789, 3406.789, 3450.789, 3456.089, 3056.709, 3400.709, 3000.009 (and other variations) all have 7 sig figs

- Zeros up front ("leading zeros") don't count
  - 03456 and 0003456 are the same numerically as 3456.
    - all have 4 sig figs.
  - Sometimes your calculator, instrument, or odometer will print out leading zeros. Just ignore these.

Counting sig figs II

- Trailing zeros (at end of number) are significant <u>only</u> if there is a decimal point
  - 1.500 has 4 sig fig
    - precise to ±0.001 (last digit is a guess)
    - Assume the true value is between 1.499 and 1.501
  - 1500 has only 2 sig figs
    - Precise to the hundreds digit (second from left) or ±100
    - Assume the true value is between 1400 and 1600
  - 1500. has 4 sig figs
    - Note the "dot" or decimal after the last zero!
    - Special notation for Chem 30A. (Scientific notation is better.)
    - Here, implies precision to the ones digit or ± 1
    - Assume the true value is between 1499 and 1500

Summary of zeros



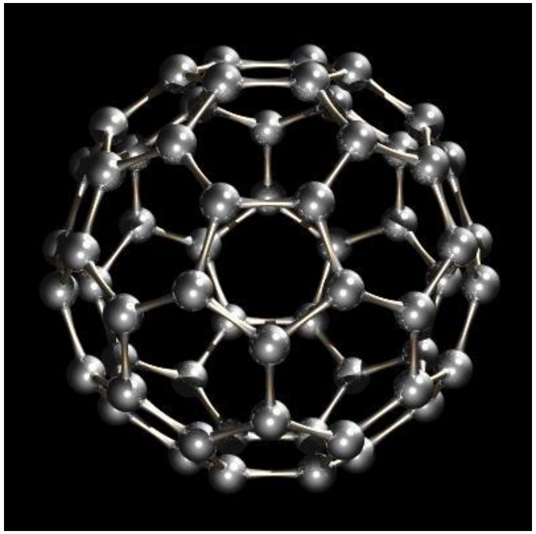
The dot (for Intro Chem only!!!)

- What's the distance to the sun?
  - 150. million kilometers (note the dot – 3 sig fig)
  - or 150. x 10^6 kilometers
  - or 1.50 x 10^2 x 10^6 kilometers
  - or 1.50 x 10^8 kilometers

- 1.50 x 10^8 km clearly has 3 sig figs
  - 150,000,000 km would be ambiguous (looks like 2 sig fig??)
  - **Scientific notation is vastly superior to the "dot" notation**
  - Especially for really big or really small numbers

Exact numbers

- Some numbers are exact.
  - There is no guess here. All digits are significant.
  - Counting
    - There are 32 students in the classroom. (2 sig fig)
    - There are 30 students in the classroom. (also 2 sig fig)
    - Buckminsterfullerene is a molecule with 60 carbons (2 sig fig)
  - Definition
    - A triangle has (exactly) 3 sides
    - 1 inch = 2.54 cm (exactly by definition)
    - Diameter of a circle is half (½) the radius.



Buckminsterfullerene (C_{60})

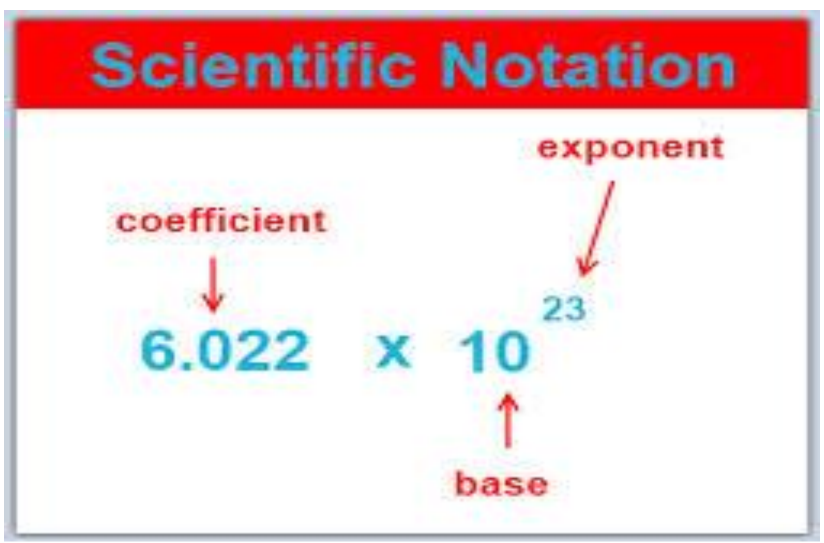
1.10 Scientific Notation *[study at home]*

- Technique used to express very large or very small numbers.
- Expresses a number as a product of a number between 1 and 10 and the appropriate power of 10.

$$93{,}000{,}000 = 9.3 \times 10{,}000{,}000 = 9.3 \times 10^7$$

Number between 1 and 10

Appropriate power of 10 $(10{,}000{,}000 = 10^7)$



Using Scientific Notation

- If the decimal point is moved to the left, the power of 10 is positive.

$$345 = 3.45 \times 10^{2}$$

- If the decimal point is moved to the right, the power of 10 is negative.

$$0.0671 = 6.71 \times 10^{-2}$$

That's a wrap!

- Get started with Homework #1 while the material is fresh.
  - Be sure to do your own work
- Studying while lecture material is fresh will greatly reduce your required study time!
- If you get stuck with the homework, ask for help from your professor (email), a classmate, a friend, or tutor.
- Bring printouts (lab manual, lecture notes, HW #2) to the next class meeting.
- Consider reading through Ch 2.3 (isotopes) before next class meeting.