Principles of Chemistry

Unit 1, Lecture 1

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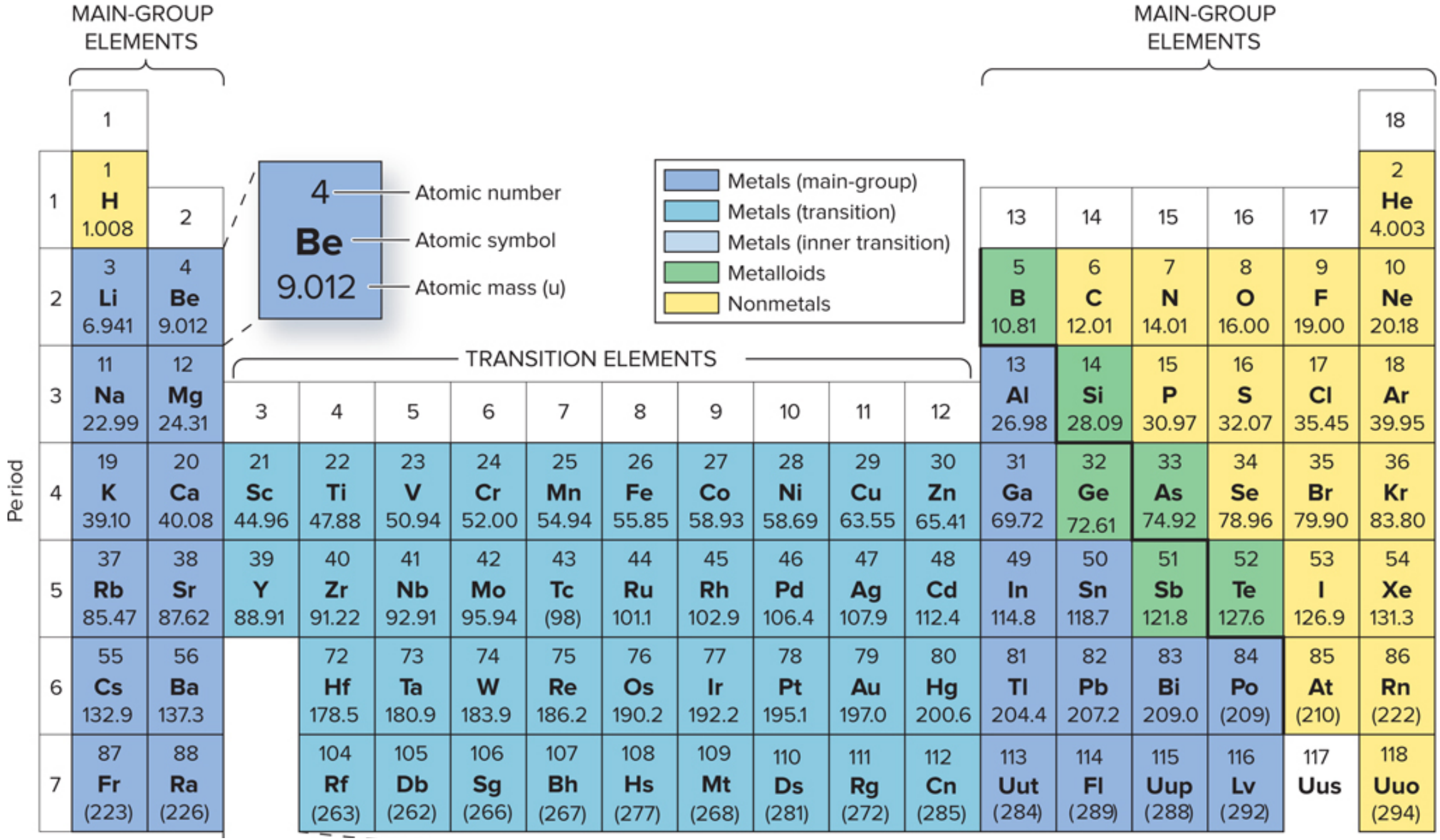
9 Sep 2019

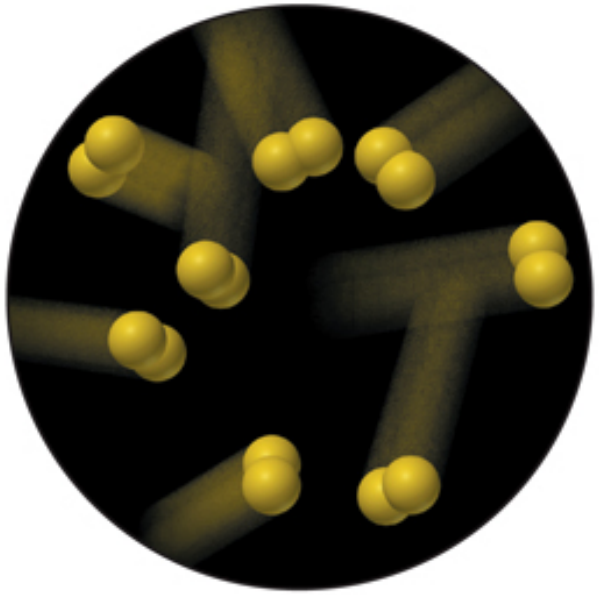

MAIN-GROUP ELEMENTS
MAIN-GROUP ELEMENTS
4
Be
9.012
Atomic number
Atomic symbol
Atomic mass (u)
Metals (main-group)
Metals (transition)
Metals (inner transition)
Metalloids
Nonmetals
TRANSITION ELEMENTS
Period
1 1 H 1.008
2 3 Li 6.941 4 Be 9.012
3 11 Na 22.99 12 Mg 24.31
4 19 K 39.10 20 Ca 40.08 21 Sc 44.96 22 Ti 47.88 23 V 50.94 24 Cr 52.00 25 Mn 54.94 26 Fe 55.85 27 Co 58.93 28 Ni 58.69 29 Cu 63.55 30 Zn 65.41 31 Ga 69.72 32 Ge 72.61 33 As 74.92 34 Se 78.96 35 Br 79.90 36 Kr 83.80
5 37 Rb 85.47 38 Sr 87.62 39 Y 88.91 40 Zr 91.22 41 Nb 92.91 42 Mo 95.94 43 Tc (98) 44 Ru 101.1 45 Rh 102.9 46 Pd 106.4 47 Ag 107.9 48 Cd 112.4 49 In 114.8 50 Sn 118.7 51 Sb 121.8 52 Te 127.6 53 I 126.9 54 Xe 131.3
6 55 Cs 132.9 56 Ba 137.3 72 Hf 178.5 73 Ta 180.9 74 W 183.9 75 Re 186.2 76 Os 190.2 77 Ir 192.2 78 Pt 195.1 79 Au 197.0 80 Hg 200.6 81 Tl 204.4 82 Pb 207.2 83 Bi 209.0 84 Po (209) 85 At (210) 86 Rn (222)
7 87 Fr (223) 88 Ra (226) 104 Rf (263) 105 Db (262) 106 Sg (266) 107 Bh (267) 108 Hs (277) 109 Mt (268) 110 Ds (281) 111 Rg (272) 112 Cn (285) 113 Uut (284) 114 Fl (289) 115 Uup (288) 116 Lv (292) 117 Uus 118 Uuo (294)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
2 He 4.003
5 B 10.81 6 C 12.01 7 N 14.01 8 O 16.00 9 F 19.00 10 Ne 20.18
13 Al 26.98 14 Si 28.09 15 P 30.97 16 S 32.07 17 Cl 35.45 18 Ar 39.95

Matter is comprised of elements

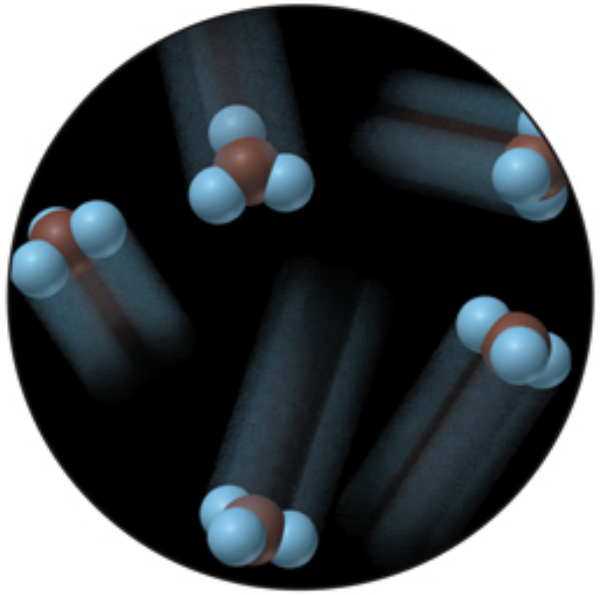
- **Matter:** Anything that occupies space and has mass
- **Atomic element:** The simplest form of matter that has specific chemical and physical properties
- **Molecular element (molecule):** two or more atoms of an element bound together (ie; O_2, H_2, Cl_2, P_4, etc.)
- **Compound (or molecules of a compound):** two or more different elements bound together (ie: H_2O)

Atoms, Elements, etc.

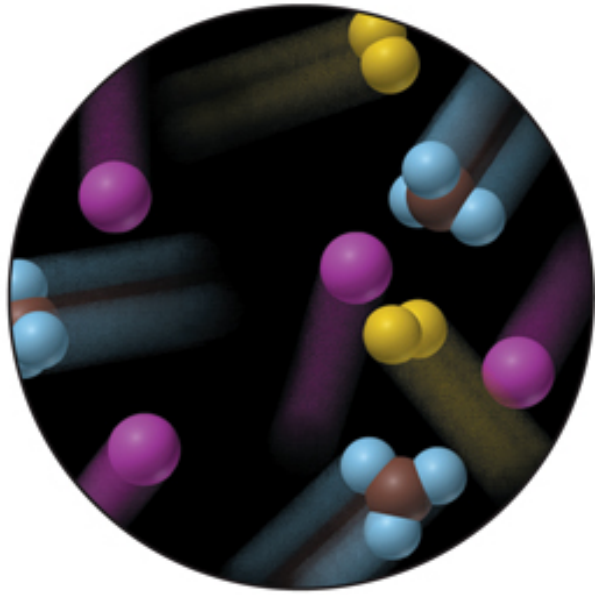
A Atoms of an element



B Molecules of an element



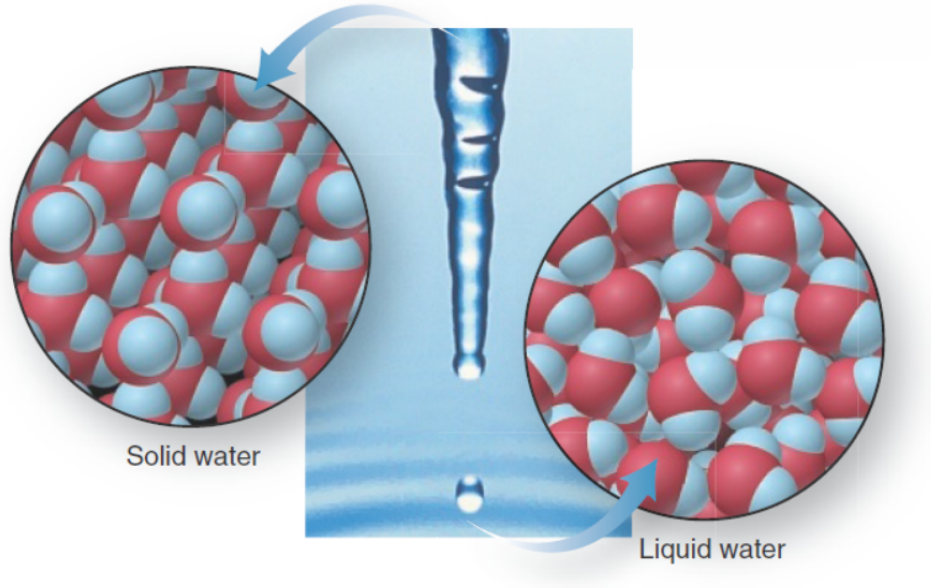
C Molecules of a compound

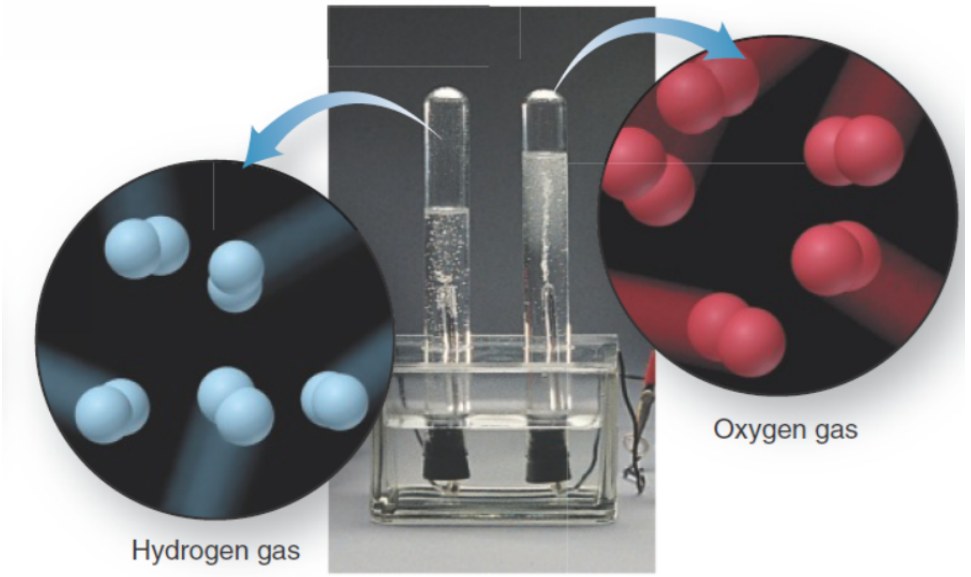


D Mixture of two elements and a compound

Matter can have physical and chemical properties

- The physical and chemical properties of matter can be understood by observation!





- **Physical properties:** Texture, hardness, odor, melting point, boiling point, color, viscosity, etc.
- **Chemical properties:** Reactivity, corrosion, flammability (air, water, acid, etc.)

Physical and Chemical Observation of Copper

Easily shaped into sheets (malleable) and wires (ductile)

Slowly forms a blue-green carbonate in moist air

Can be melted and mixed with zinc to form brass

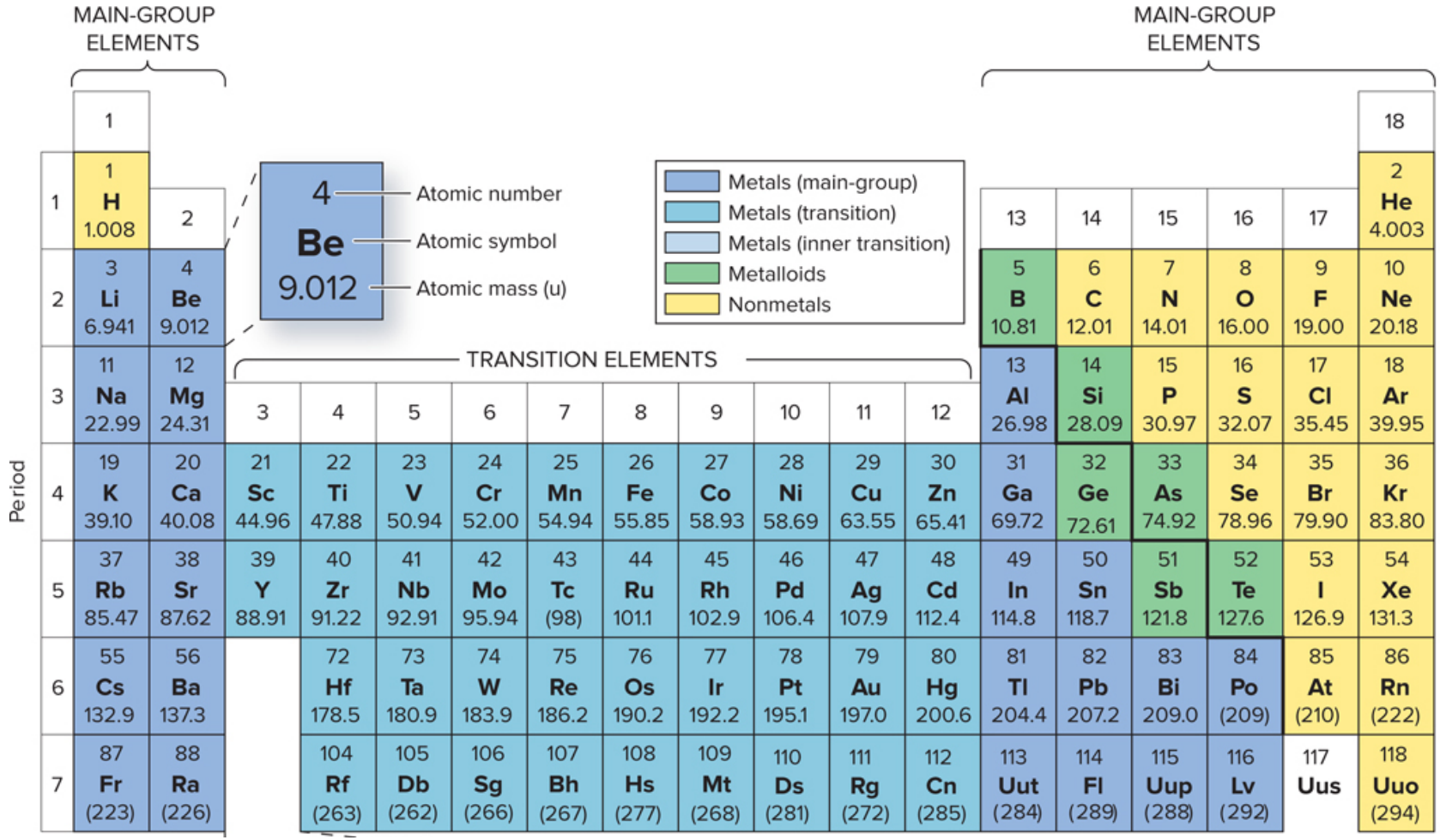
Density = 8.95 g/cm^3
Melting point = 1083°C
Boiling point = 2570°C

Reacts with nitric or sulfuric acid

Slowly forms a deep-blue solution in aqueous ammonia

Naming molecules and compounds

- Chemists don’t walk around naming molecules based on their molecular formula!



Naming molecules and compounds

- There are three distinct naming categories:
  - Binary (two) ionic compounds
  - Ternary (polyatomic) ionic compounds
  - Molecular compounds

- **Note:** When writing out the molecular formulas from the chemical name, consider the following:
  - The subscript refers to the element preceding it (subscript is generally the charge of the preceding element)
  - The subscript must be reduced to the smallest whole number (compound generally must be neutral)

  - **For example:** $MgCl_2$

Binary ionic compounds (Group 1, 2, & 13 cations)

- Naming?
  - Cation comes first (name on the periodic table)
  - Anion comes second with the ending "*-ide*"

- **For example:**
  - NaCl
  - HCl
  - CaS
  - Aluminium sulfide

Binary ionic compounds (transitions metals)

- Naming?
  - The highest charge gets the ending "*-ic*"
  - The lowest charge gets the ending "*-ous*"
- **For example:**
  - $FeCl_3$
  - CuS
  - $SnCl_4$
  - SnO_2

Element	Ion Formula	Systematic Name	Common (Trivial) Name
Chromium	Cr^{2+}	Chromium(II)	Chromous
	Cr^{3+}	**Chromium(III)**	Chromic
Cobalt	Co^{2+}	Cobalt(II)	
	Co^{3+}	Cobalt(III)	
Copper	**Cu^{+}**	**Copper(I)**	Cuprous
	Cu^{2+}	**Copper(II)**	Cupric
Iron	**Fe^{2+}**	**Iron(II)**	Ferrous
	Fe^{3+}	**Iron(III)**	Ferric
Lead	**Pb^{2+}**	**Lead(II)**	
	Pb^{4+}	Lead(IV)	
Mercury	Hg_2^{2+}**	Mercury(I)	Mercurous
	Hg^{2+}	**Mercury(II)**	Mercuric
Tin	**Sn^{2+}**	**Tin(II)**	Stannous
	Sn^{4+}	Tin(IV)	Stannic

Ternary ionic compounds

- Ionic compounds are often ternary (polyatomic) compounds like NH_4Cl (ammonium chloride)
- Ternary compounds are composed of:
  - Two distinct compounds held together by opposite charges (NH_4NO_3)
  - One compound bound to an element through opposite charges (NH_4Cl or KNO_3)
- ***How can you tell the difference between a binary ionic compound and a ternary ionic compound?***

$MgCl_2$ KNO_3

Ternary cationic and anionic complexes

- To determine the name of a ternary anionic complex:
  - The one with the most oxygens: *-ate*
  - The one with the least oxygens: *-ite*

- **For example:**
  - NO_3^- vs. NO_2^-

CH_3COO^- (or **$C_2H_3O_2^-$**)	**Ethanoate (or Acetate)**	CrO_4^{2-}	Chromate
CN^-	Cyanide	**$Cr_2O_7^{2-}$**	**Dichromate**
OH^-	**Hydroxide**	O_2^{2-}	Peroxide
ClO^-	Hypochlorite	**PO_4^{3-}**	**Phosphate**
ClO_2^-	Chlorite	HPO_4^{2-}	Hydrogen phosphate
ClO_3^-	**Chlorate**	$H_2PO_4^-$	Dihydrogen phosphate
ClO_4^-	**Perchlorate**	SO_3^{2-}	Sulfite
NO_2^-	Nitrite	**SO_4^{2-}**	**Sulfate**
NO_3^-	**Nitrate**	HSO_4^-	Hydrogen sulfate (or bisulfate)
MnO_4^-	**Permanganate**		
CO_3^{2-}	**Carbonate**		
HCO_3^-	**Hydrogen carbonate** (or **bicarbonate**)		

Naming ternary ionic compounds

- Naming?
  - Naming ternary ionic compounds is the similar to binary ionic: cation comes first, followed by anion (except that the anionic ending depends on species)
  - If you have two compounds in a ternary ionic compound, then you may have to use parenthesis. For example, consider calcium nitrate:
  - Hydrated compounds are called **hydrates**

Naming molecular compounds

- Molecular compounds consist of a combination of different non-metal elements

- Naming?
  - Elements in the higher group comes second and is named with its root and suffix "-*ide*". Example: SiO_2

  - If both elements are in the same group, the element with the higher period number is named first. For example, consider SO_3

Summary

- When determine the molecular formula, the overall charges for the compound must be **neutral** (use periodic table to determine oxidation state)

- Binary ionic compound consist of a **non-metal** and a **metal**
  - Binary ionic compounds have the anionic ending "*-ide*"

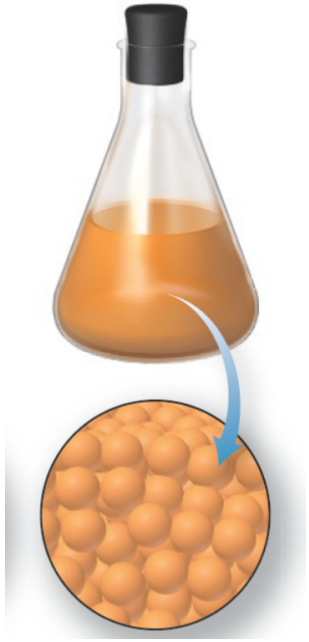
- The ternary ionic compounds contain **non-metal compounds (either one or two)**
  - Ternary ionic compound ending can be "*-ide*", "*-ite*", or "*-ate*"

- Covalent compounds consists of only **non-metals**

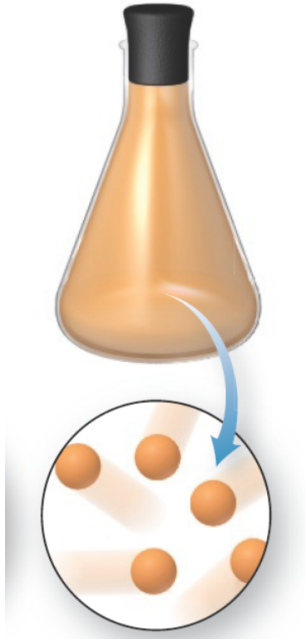
States of Matter

- There exists 3 states of matter relevant to general chemistry (***animation here***)

Solid
Low kinetic energy

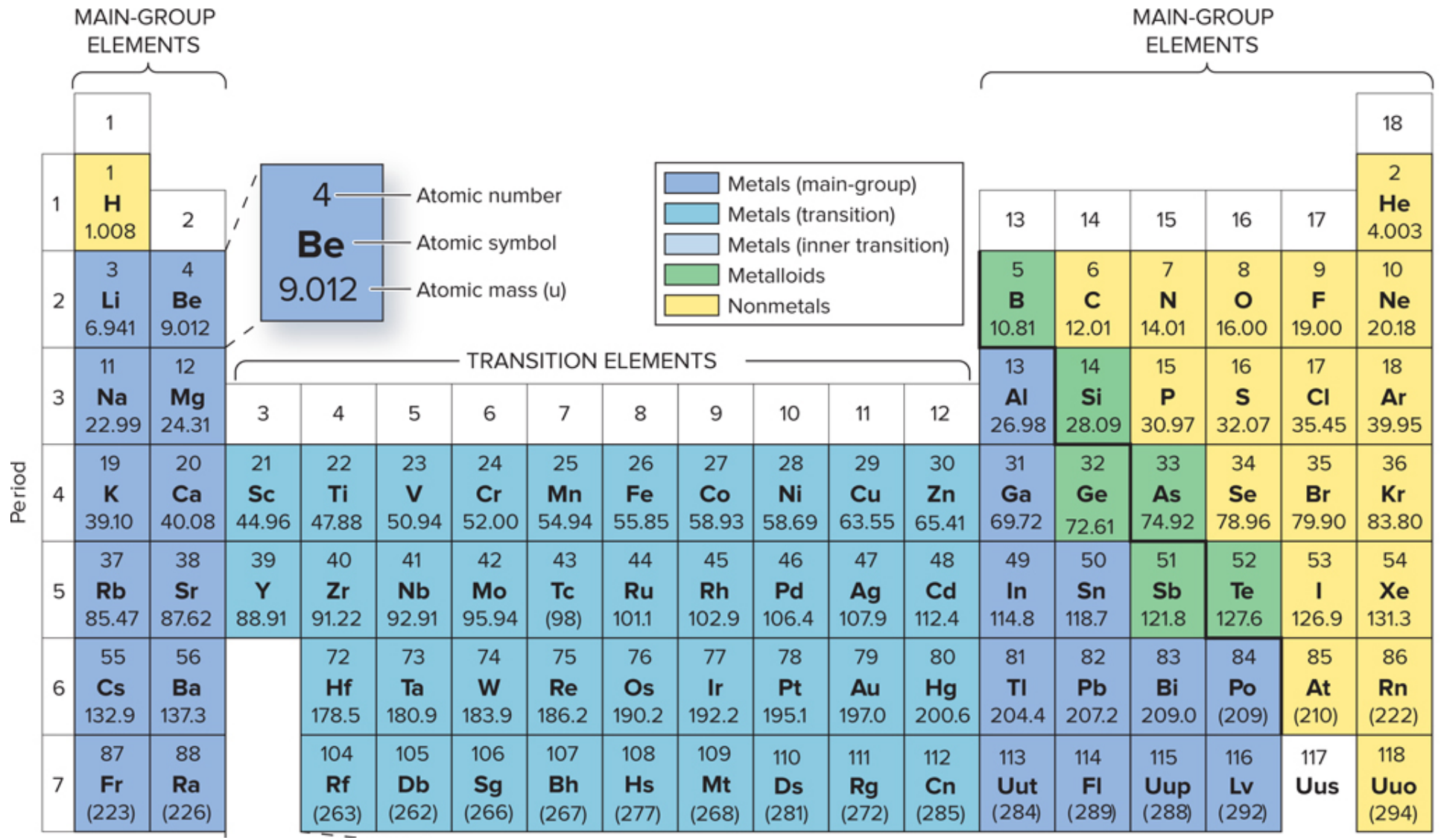


Liquid
Medium kinetic energy

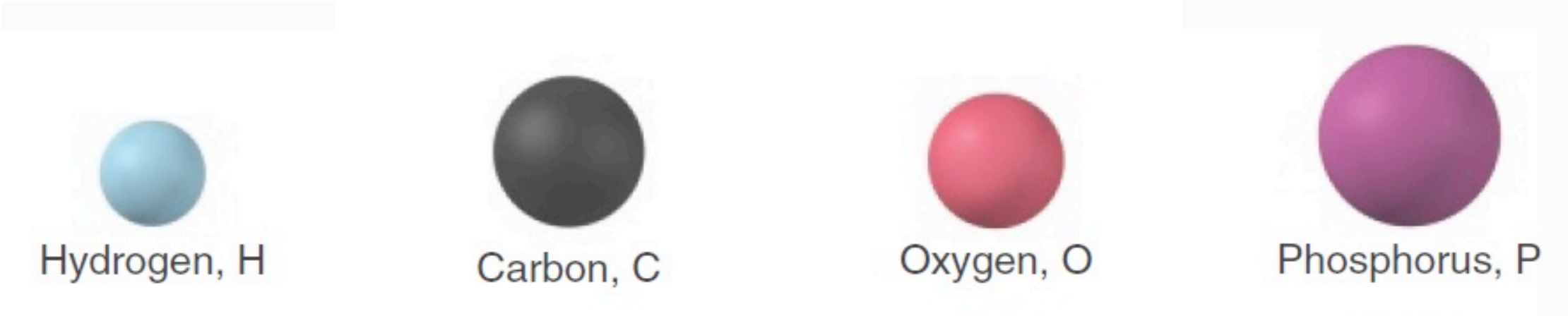


Gas
High kinetic energy

The mass of elements



The ***molar*** mass of elements



- Because elements are matter, they have a mass!
- **Molar mass:** the mass (in grams) of 1 mole of a given element
- **Mole:** the amount of a substance (using Avogadro's number: 6.02×10^{23})
- *Why do the molar masses of compounds differ if all the elements have the name number of particles?*

Molar mass of elements and compounds

- Molar mass lets us relate the number of particles/entities to the mass of a sample of particles/entities
  - Will be important when we talk shortly about dimensional analysis

- To calculate molar mass, use the periodic table and a calculator.

- **For example:**
  - SO_2
  - CO_2
  - H_2O_2

Don’t forget about significant figures!

- **How to determine the number of significant figures:**
  - Any digit that is not zero is significant:

    845 cm 1.234 kg
  - Zeros between non-zeros are significant:

    8405 cm 1.00234 kg
  - Zeroes to the left of the first non-zero are not significant:

    0.845 cm 0.00234 kg
  - If number is greater than 1? Zeros to the right of the decimal point are significant:

    13.000000 kg 1034.0 g
  - If number if less than 1? Zeros between non-zeros and/or at the end of numbers are significant:

    0.00100000 kg 0.0340034 g

Trailing zeroes & rules for arithmetic calculations

- Numerical values with no decimal points? Trailing zeros are <u>not significant:</u>

10045000 kg 45000 kg 450001 kg

- **Multiplication and division:**
  - Answer must contain the same number of sigfigs as the measurement with the *fewest significant figures*
  - **For example:** 9.2 cm x 6.8 cm x 0.3744 cm = 23.422464 cm^3 or 23 cm^3

- **Addition and subtraction:**
  - Same number of decimal places as the measurement with the fewest decimal places
  - **For example:** 83.5 ml + 23.28 ml = 106.78 ml or 106.8 ml

Don’t forgot about SI units

- In science, the metric system is the numerical system of choice
- The SI system is based on 7 fundamental units:

TABLE 1.2 SI Base Units

Physical Quantity (Dimension)	Unit Name	Unit Abbreviation
Mass	kilogram	kg
Length	metre	m
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Amount of substance	mole	mol
Luminous intensity	candela	Cd

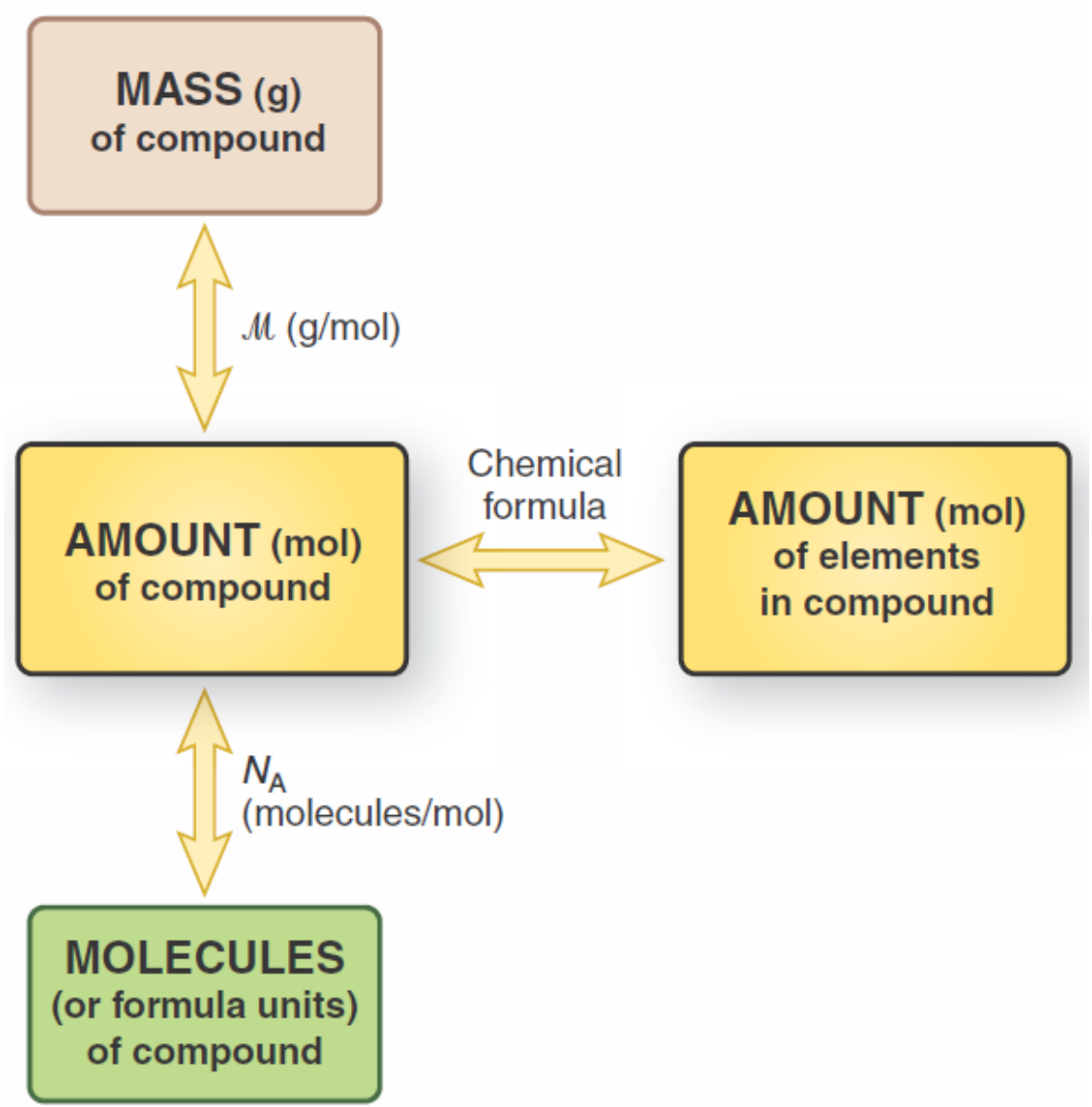
Why we care about units (show video)….

Remember the Mars Climate Orbiter incident from 1999?

Summary

- There are three states of matter: solid, liquid, gas
- Molar mass is the mass of 1 mole (N_A) of an element
- The molar mass will vary depending on the element (more protons, neutrons, electrons = heavier)
- Sigfigs are important in determining the uncertainty of a calculation
- The metric system (SI units) are used in chemistry to perform calculations

Dimensional analysis: converting between values



Dimensional analysis and chemical calculations

- In chemistry, we need to make sure reactions are successful. One of the ways we do this is by calculating the amount of the product formed vs. the amount of the reactant used.
  - To do this, we need to know how to interconvert between units.

- **Hint:**
  - When converting between units, make sure the numerator cancels out the dominator (may have to multiply or divide)

  - Make sure the final unit is in the numerator

- **SUPER HINT:**

Dimensional analysis: Example 1

Graphite (C) is the crystalline form of carbon that is used in pencils. What amount of carbon (mol) is in 315 mg of graphite?

Dimensional analysis: Example 2

345 g of potassium nitrate has been weight for a specific reaction. Calculate the following:

1. The amount (mol) of potassium nitrate
2. The amount (mol) of potassium in potassium nitrate
3. The amount (g) of potassium in potassium nitrate

Dimensional analysis: Example 2

345 g of potassium nitrate has been weight for a specific reaction. Calculate the following:

1. The amount (mol) of potassium nitrate
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3. The amount (g) of potassium in potassium nitrate

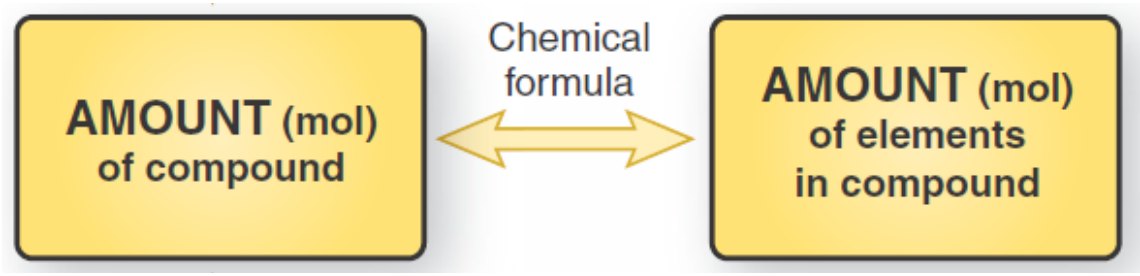
Dimensional analysis: Example 2

345 g of potassium nitrate has been weight for a specific reaction. Calculate the following:

1. The amount (mol) of potassium nitrate
2. The amount (mol) of potassium in potassium nitrate
3. The amount (g) of potassium in potassium nitrate

Percent composition by mass

- Each element in a chemical compounds contributes a specific percent mass to a chemical compound.
- **Key point to understand:**



- **Percent mass of an atom in a compound:**

Percent composition by mass: variation 1

- Each element in a chemical compounds contributes a specific percent mass to a chemical compound.

- **For example (variation 1):** Calculate the percent mass of potassium in KCl

Percent composition by mass: variation 2

- Each element in a chemical compounds contributes a specific percent mass to a chemical compound.

- **For example (variation 2):** Calculate the percent mass of potassium in ***4.56g*** of KCl

Empirical vs. Molecular Formula

- What is the difference between the empirical and molecular formula?

- **Empirical formula:** Derived from mass analysis (combustion analysis) and shows the lowest whole number of moles

- **Molecular formula:** Show the actual number of atoms in each element

Determination of the empirical formula

- **To determine the empirical formula:**
  - Determine the mass of each component element
  - Convert mass to the mole and propose a formula
  - Convert mol to whole number and divide by the smallest value

Empirical formula: example

A sample of a white solid contains 0.170 mol of boron and 0.255 mol of hydrogen. What is the empirical formula?

Determination of the molecular formula

- **To determine the molecular formula:**
  - Assume 100 g of a compound to express each mass percent directly as mass
  - Convert each mass to mol
  - Derive the empirical formula
  - Divide the molar mass of the compound by the empirical formula to find the whole-number multiple
  - Multiply each subscript in the empirical formula by the whole number multiple to ID the molecular formula

Molecular formula: example

One of the most widespread environmental carcinogens, or cancer-causing agents, is benzo[a]pyrene. It is found in coal dust, cigarette smoke, and charcoal grilled meat. Analysis of this hydrocarbon shows 95.21% mass of C and 4.79% mass of H. What is the molecular formula given the molar mass of 252.31 g/mol?

Molecular formula: example cont’d

One of the most widespread environmental carcinogens, or cancer-causing agents, is benzo[a]pyrene. It is found in coal dust, cigarette smoke, and charcoal grilled meat. Analysis of this hydrocarbon shows 95.21% mass of C and 4.79% mass of H. What is the molecular formula given the molar mass of 252.31 g/mol?

Lecture summary

- Determine the percent composition by mass of the component elements given the molecular or empirical formula of a compound
- Determine the empirical formula for a compound given its percent composition by mass
- Determine the molecular formula of a compound given its empirical formula and molecular weight
- Post-lecture quiz 1:
  - 1 empirical formula question
  - 1 molecular formula question
  - 1 % mass question