What is stoichiometry?

- (Probably) the most important topic in chemistry!
- This is the basis for **many** subsequent chapters
- Related to the *amount* of a species or substance
- Sometimes referred to as the mathematics of chemistry

Some definitions

- Molar mass (aka molecular weight) – sum of atomic masses (weights) for all the atoms in a given molecule.
  - Use the periodic table and the molecular formula to determine this
- Formula mass (formula weight) – sum of the masses for all the ions in a given formula unit

The periodic table

PERIODIC CHART OF THE ELEMENTS

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	INERT GASES
1 H 1.00797																1 H 1.00797	2 He 4.0026
3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.0112	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.183
11 Na 22.9898	12 Mg 24.312											13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.909	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.905	46 Pd 106.4	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.904	54 Xe 131.30
55 Cs 132.905	56 Ba 137.34	*57 La 138.91	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	†89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 ? (271)	111 ? (272)	112 ? (277)						

Numbers in parenthesis are mass numbers of most stable or most common isotope.

Atomic weights corrected to conform to the 1963 values of the Commission on Atomic Weights.

The group designations used here are the former Chemical Abstract Service numbers.

* Lanthanide Series

58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm (147)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.97

† Actinide Series

90 Th 232.038	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (256)	103 Lr (257)

An Important Interpretation

- The stoichiometric coefficients that are present in a balanced chemical reaction are related to the *ratios* of reactants and products in a chemical reaction
- This ratio is only in terms of moles (or molecules), BUT NOT mass!

Example

- The final step in the production of nitric acid involves the reaction of nitrogen dioxide with water; nitrogen monoxide is also produced. How many grams of nitric acid are produced for every 100.0 g of nitrogen dioxide that reacts?

Solution

- Step 1: Write down the chemical reaction
  - $NO_2 + H_2O \rightarrow HNO_3 + NO$
- Step 2: Balance the chemical reaction
  - $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$
- Step 3: Determine the moles of NO_2 that will react
  - 100 g NO_2 / 46.006 g/mol = 2.174 mol NO_2

Solution (continued)

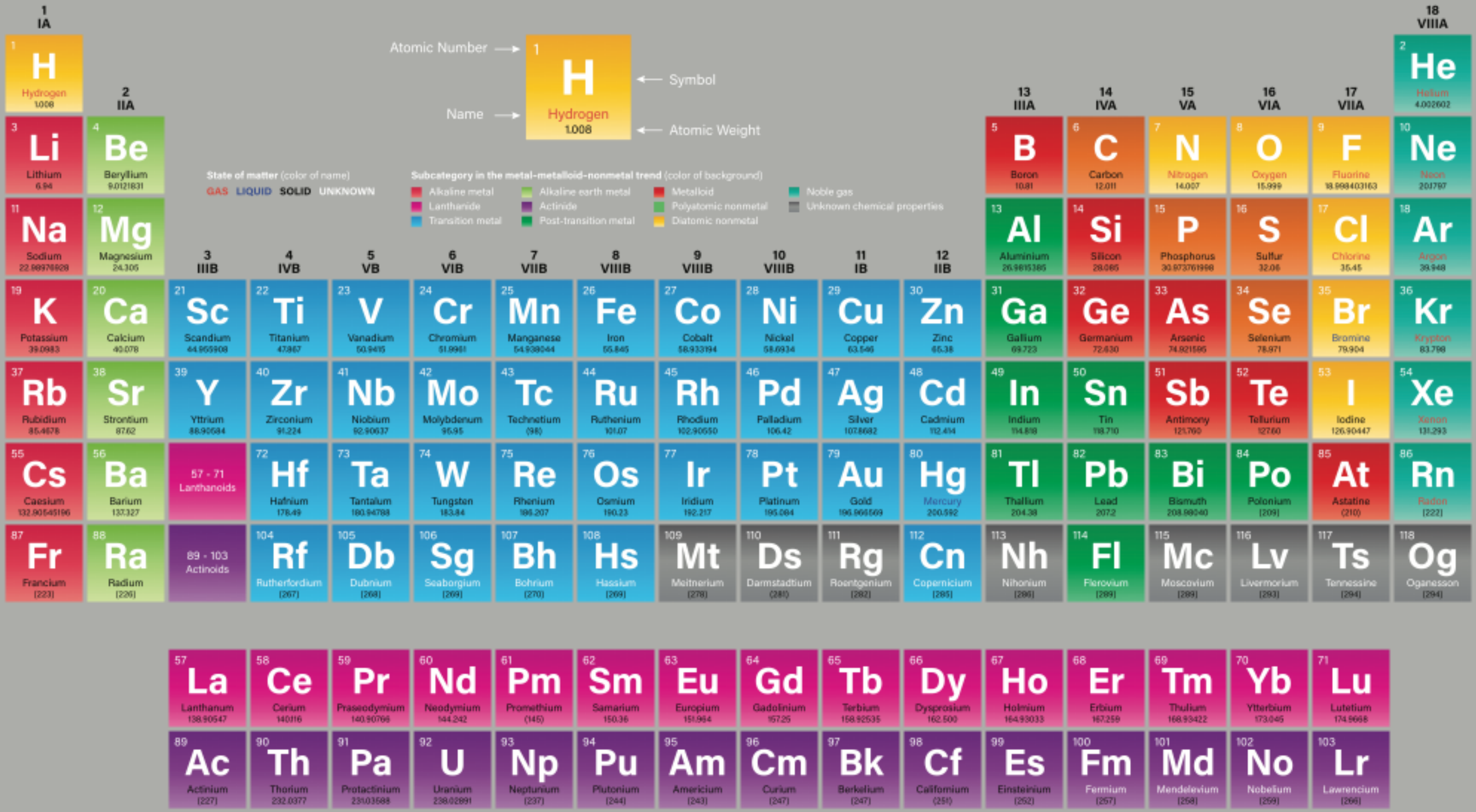
- Step 4: Use stoichiometry to determine the moles of HNO_3 that will be produced

$$\frac{NO_2}{HNO_3} = \frac{3}{2} = \frac{2.174\ mol}{x}$$

  Solving for x, x = 1.449 mol HNO_3

- Step 5: Convert to grams of nitric acid
  - 1.449 mol HNO_3 * 63.013 g/mol = 91.31 g HNO_3

Using the periodic table, predict whether the following chlorides are ionic or covalent: KCl, NCl_3, ICl, $MgCl_2$, PCl_5, and CCl_4.



Atomic Number
Symbol
Name
Atomic Weight
1 H Hydrogen 1.008
State of matter (color of name)
GAS LIQUID SOLID UNKNOWN
Subcategory in the metal-metalloid-nonmetal trend (color of background)
Alkaline metal
Alkaline earth metal
Metalloid
Noble gas
Lanthanide
Actinide
Polyatomic nonmetal
Unknown chemical properties
Transition metal
Post-transition metal
Diatomic nonmetal
1 IA
2 IIA
3 IIIB
4 IVB
5 VB
6 VIB
7 VIIB
8 VIIIB
9 VIIIB
10 VIIIB
11 IB
12 IIB
13 IIIA
14 IVA
15 VA
16 VIA
17 VIIA
18 VIIIA
1 H Hydrogen 1.008
2 He Helium 4.002602
3 Li Lithium 6.94
4 Be Beryllium 9.0121831
5 B Boron 10.81
6 C Carbon 12.011
7 N Nitrogen 14.007
8 O Oxygen 15.999
9 F Fluorine 18.998403163
10 Ne Neon 20.1797
11 Na Sodium 22.98976928
12 Mg Magnesium 24.305
13 Al Aluminium 26.9815385
14 Si Silicon 28.085
15 P Phosphorus 30.973761998
16 S Sulfur 32.06
17 Cl Chlorine 35.45
18 Ar Argon 39.948
19 K Potassium 39.0983
20 Ca Calcium 40.078
21 Sc Scandium 44.955908
22 Ti Titanium 47.867
23 V Vanadium 50.9415
24 Cr Chromium 51.9961
25 Mn Manganese 54.938044
26 Fe Iron 55.845
27 Co Cobalt 58.933194
28 Ni Nickel 58.6934
29 Cu Copper 63.546
30 Zn Zinc 65.38
31 Ga Gallium 69.723
32 Ge Germanium 72.630
33 As Arsenic 74.921595
34 Se Selenium 78.971
35 Br Bromine 79.904
36 Kr Krypton 83.798
37 Rb Rubidium 85.4678
38 Sr Strontium 87.62
39 Y Yttrium 88.90584
40 Zr Zirconium 91.224
41 Nb Niobium 92.90637
42 Mo Molybdenum 95.95
43 Tc Technetium (98)
44 Ru Ruthenium 101.07
45 Rh Rhodium 102.90550
46 Pd Palladium 106.42
47 Ag Silver 107.8682
48 Cd Cadmium 112.414
49 In Indium 114.818
50 Sn Tin 118.710
51 Sb Antimony 121.760
52 Te Tellurium 127.60
53 I Iodine 126.90447
54 Xe Xenon 131.293
55 Cs Caesium 132.90545196
56 Ba Barium 137.327
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72 Hf Hafnium 178.49
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75 Re Rhenium 186.207
76 Os Osmium 190.23
77 Ir Iridium 192.217
78 Pt Platinum 195.084
79 Au Gold 196.966569
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81 Tl Thallium 204.38
82 Pb Lead 207.2
83 Bi Bismuth 208.98040
84 Po Polonium [209]
85 At Astatine (210)
86 Rn Radon [222]
87 Fr Francium [223]
88 Ra Radium [226]
89 - 103 Actinoids
104 Rf Rutherfordium [267]
105 Db Dubnium [268]
106 Sg Seaborgium [269]
107 Bh Bohrium [270]
108 Hs Hassium [269]
109 Mt Meitnerium [278]
110 Ds Darmstadtium [281]
111 Rg Roentgenium [282]
112 Cn Copernicium [285]
113 Nh Nihonium [286]
114 Fl Flerovium [289]
115 Mc Moscovium [289]
116 Lv Livermorium [293]
117 Ts Tennessine [294]
118 Og Oganesson [294]
57 La Lanthanum 138.90547
58 Ce Cerium 140.116
59 Pr Praseodymium 140.90766
60 Nd Neodymium 144.242
61 Pm Promethium (145)
62 Sm Samarium 150.36
63 Eu Europium 151.964
64 Gd Gadolinium 157.25
65 Tb Terbium 158.92535
66 Dy Dysprosium 162.500
67 Ho Holmium 164.93033
68 Er Erbium 167.259
69 Tm Thulium 168.93422
70 Yb Ytterbium 173.045
71 Lu Lutetium 174.9668
89 Ac Actinium [227]
90 Th Thorium 232.0377
91 Pa Protactinium 231.03588
92 U Uranium 238.02891
93 Np Neptunium [237]
94 Pu Plutonium [244]
95 Am Americium [243]
96 Cm Curium [247]
97 Bk Berkelium [247]
98 Cf Californium [251]
99 Es Einsteinium [252]
100 Fm Fermium [257]
101 Md Mendelevium [258]
102 No Nobelium [259]
103 Lr Lawrencium [266]

Limiting and Excess Reagents (Reactants)

- Equivalent – a mathematically equal amount of a chemical substance (in terms of moles)
- Sometimes you don't have the "stoichiometrically correct" number of equivalents
  - Cost
  - Availability
  - Reaction conditions
- Limiting – gets used up entirely
- Excess – remaining (left over)

More on limiting reagents

- This is based on the # of moles in a **balanced** chemical reaction
  - You *cannot* simply look at # of moles directly, or the mass (grams) that are given.
- The limiting reagent *always* determines the outcome of a chemical reaction
  - # of moles (or grams) of product that can be formed

Example

- Magnesium nitride can be formed by the reaction of magnesium metal with nitrogen gas.
- A) How many grams of magnesium nitride can be made in the reaction of 35.00 g of magnesium and 15.00 g of nitrogen?
- B) How many grams of the excess reactant remain after the reaction?

Solution (part a)

- Step 1: Write down (and balance) the chemical reaction
  - $3Mg + N_2 \rightarrow Mg_3N_2$
- Step 2: Find the # of moles of each reactant. This represents the moles you HAVE.
  - mol Mg = 35.00 g / 24.305 g/mol = 1.440 mol Mg
  - mol N_2 = 15.00 g / 28.013 g/mol = 0.5355 mol N_2

Solution (part a)

- Step 3: Pick *one* reactant, and find the number of moles of the *other* using stoichiometry. This represents the moles you NEED.

$$\frac{Mg}{N_2} = \frac{3}{1} = \frac{1.440\ mol}{x}$$

Solving for x, x = 0.4800 mol N_2

Solution (part a)

- Step 4: Compare the moles you HAVE with the moles you NEED. If HAVE > NEED, this is in *excess*. If you HAVE < NEED, this is *limiting*.
  - We have 0.5355 mol N_2 and need 0.4800 mol of N_2, so N_2 must be in excess. Therefore Mg is limiting.

Solution (part a)

- Step 5: Using the limiting reactant and stoichiometry, determine the number of moles of product. $\frac{Mg}{Mg_3N_2} = \frac{3}{1} = \frac{1.440\,mol}{x}$

  Solving for x, x = 0.4800 mol Mg_3N_2.
- Step 6: Find the mass of the product
  - 0.4800 mol Mg_3N_2* 100.93 g/mol = 48.45 g Mg_3N_2

Solution (part b)

- Step 1: Determine how much N_2 (the excess reagent) is actually used.
  - 0.4800 mol N_2 * 28.013 g/mol = 13.45 g N_2
- Step 2: Determine the amount of excess.
  - 15.00 g – 13.45 g = 1.55 g N_2

An alternate solution to part b

- Conservation of mass
  - The total mass *before* the chemical reaction must be the same as the total mass *after* the chemical reaction
  - mass Mg + mass N_2 = 35.00 g + 15.00 g = 50.00 g
  - Mass of Mg_3N_2 = 48.45 g
  - Therefore mass of excess N_2 must be 50.00 – 48.45 g = 1.55 g

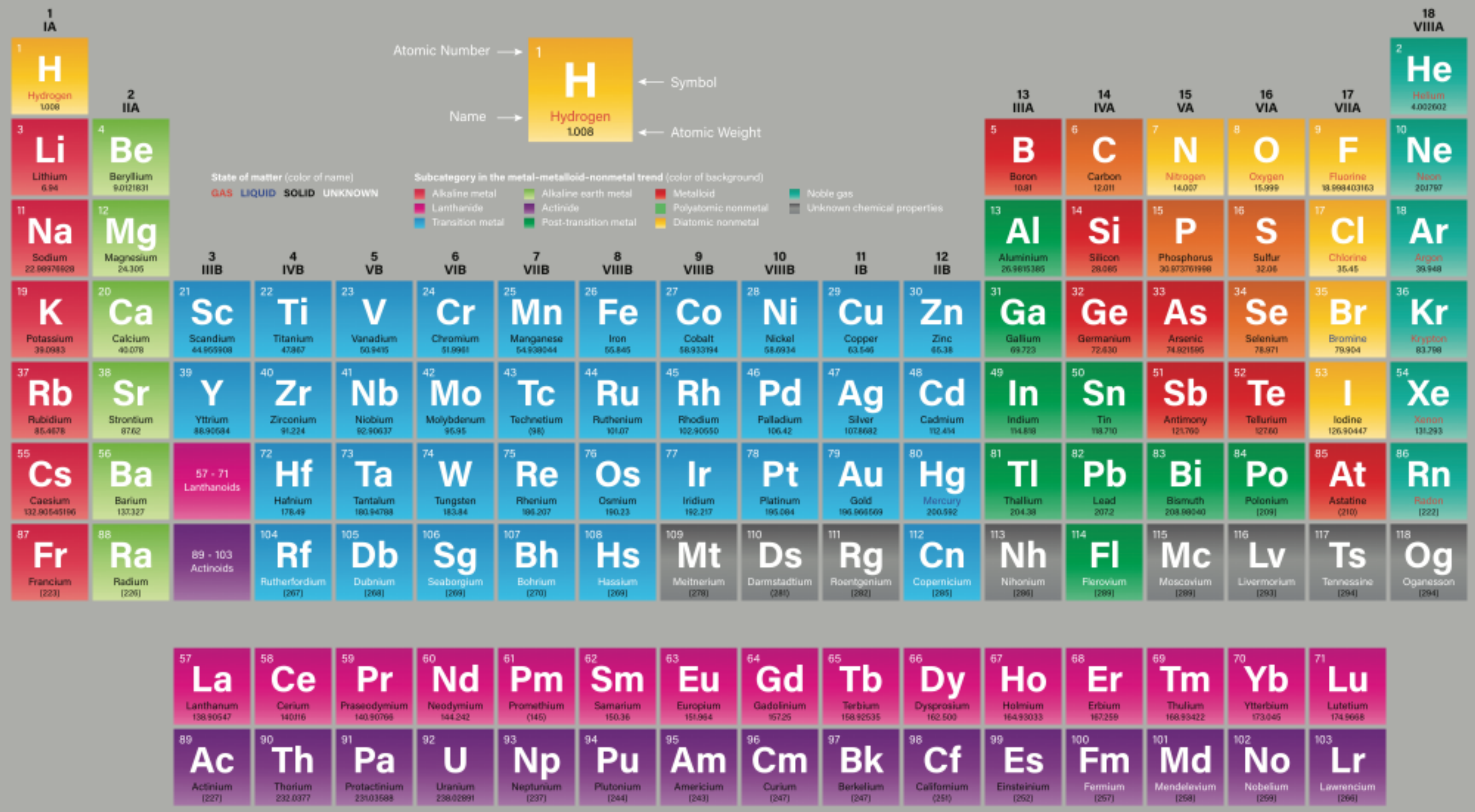
Yield

- This is related to the efficiency of a chemical reaction (how well it worked)

$$\% \, Yield = \frac{actual}{theoretical} \, X \, 100\%$$

- Actual refers to an experimental quantity
- Theoretical refers to the amount calculated using stoichiometry
- The amounts used can be mass or moles, as long as you are consistent (and both #'s refer to the product)
- Engineers usually also are concerned with *selectivity* and *conversion*.

In an accident, a solution containing 2.5 kg of nitric acid was spilled. Two kilograms of Na_2CO_3 was quickly spread on the area and CO_2 was released by the reaction. Was sufficient Na_2CO_3 used to neutralize all of the acid?



1 IA
2 IIA
3 IIIB
4 IVB
5 VB
6 VIB
7 VIIB
8 VIIIB
9 VIIIB
10 VIIIB
11 IB
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15 VA
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103 Lr Lawrencium [266]

Balancing Chemical Reactions

- The # of each type of atom must balance (conservation of mass)
  - Can use coefficients in front to make things work.
- Good rule of thumb – try to balance the atoms that show up in the least # of spots (# of compounds) 1^{st}
- It's OK to use fractions
  - If whole #'s are wanted/needed just multiply by LCD

Example: Combustion of Ethane

- Step 1: Write down the reaction
  - $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$
- Step 2: Balance the C's
  - $C_2H_6 + O_2 \rightarrow 2CO_2 + H_2O$
- Step 3: Balance the H's
  - $C_2H_6 + O_2 \rightarrow 2CO_2 + 3H_2O$
- Step 4: Balance the O's
  - $C_2H_6 + 7/2\ O_2 \rightarrow 2CO_2 + 3H_2O$
- Step 5: Use whole number coefficients (optional)
  - $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

Balancing redox reactions

- Key: The number of electrons "lost" (in an oxidation) must be the same as the number of electrons "gained" (in a reduction)

1) Determine oxidation numbers and write down the half-reactions.
2) Balance the atoms in each half-reaction (except O and H)
3) Balance the charge in each half-reaction by adding electrons.
4) Balance the total number of electrons for both half-reactions and add the two reactions.
5) Add H_2O to balance the O's (and H's).
6) If acidic, add H^+ to balance the H's.
7) If basic, add H^+ to balance the H's, then add an equal number of OH^- to both sides ($H^+ + OH^- \rightarrow H_2O$), and simplify.

Check: The total charge on the left side must be equal to the total charge on the right side of the overall reaction.

Example

- In basic solution, Br_2 disproportionates to bromide ions and bromate ions. Use the half-reaction method to balance the equation for this reaction:

$Br_2(l) \rightarrow Br^{-}(aq) + BrO_3^{-}$

Solution

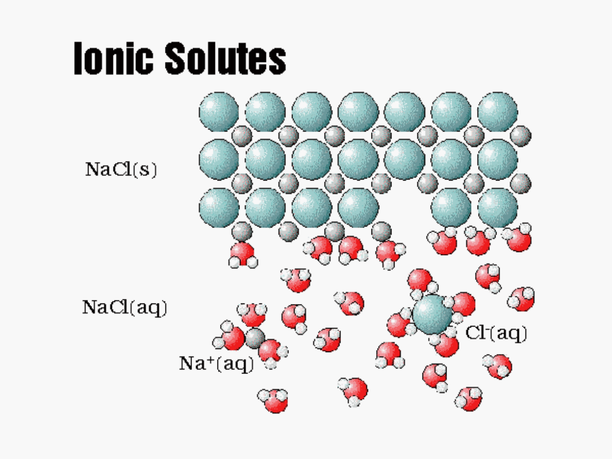
- First assign oxidation numbers to the Br's: Br_2 = 0, Br^- = -1, Br in BrO_3^- = +5 (since O has an oxidation number of -2)
- So the half-reactions are $Br_2 + 2e^- \rightarrow 2Br^-$ and $Br_2 \rightarrow 2BrO_3^- + 10e^-$
- Balance the number of electrons by multiplying the reduction reaction by 5, and add the two reactions: $6Br_2 + 10e^- \rightarrow 10Br^- + 2BrO_3^- + 10e^-$
- Simplify: $3Br_2 \rightarrow 5Br^- + BrO_3^-$
- Add H_2O to balance the O's: $3Br_2 + 3H_2O \rightarrow 5Br^- + BrO_3^-$
- Add H^+ and OH^- (since the solution is basic) to balance the H's: $3Br_2 + 3H_2O + 6OH^- \rightarrow 5Br^- + BrO_3^- + 6H^+ + 6OH^-$
- Simplify: $3Br_2 + 6OH^- \rightarrow 5Br^- + BrO_3^- + 3H_2O$
- Check: Total charge on the left = 3(0) + 6(-1) = -6, and the total charge on the right is 5(-1) + -1 +3(0) = -6

Balance the following equation according to the half-reaction method:

$Zn(s) + NO_3^-(aq) \longrightarrow Zn^{2+}(aq) + NH_3(aq)$ (in base)

Arrhenius Theory of Dissociation

- Dissociation happens spontaneously when ionic (soluble) compounds dissolve in H_2O.
- The more ions are present (i.e. the better it dissociates), the more electricity is conducted.



http://antoine.frostburg.edu/chem/senese/101/reactions/slides/sld006.htm

Classification of electrolytes

- Strong – soluble ionic substances (salts), mineral acids, bases
  - Acids: HCl, HBr, HI, HNO_3, H_2SO_4, $HClO_4$
  - Bases: LiOH, NaOH, KOH, RbOH, CsOH, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$
- Weak – carboxylic acids, amines
- Non-electrolytes – most organic compounds
- The words “strong” and “weak” refer *only* to how well something dissociates and forms ions, NOT if it is dangerous, reactive, etc.

Determining concentrations of ionic solutions

- For the [ ] of ions, we need to consider **both** the formula and whether or not it dissociates completely (strong electrolyte)