Ch. 10 – Stoichiometry

Stoichiometry – relates molar ratios between reactants and products in a chemical equation

- Used to determine moles of reactants needed
- Used to determine moles of products formed

Conservation of Mass

- When chemicals react, no matter is gained or lost (except for nuclear fusion/fission reactions)

- Reactions occur by gaining/losing or sharing electrons

  - Therefore, no elements change into other elements

  - So there should be the same number of atoms of each element on both sides of the equation

Chemical Reactions – Occur when compounds change into other compounds

- Reactants – compounds/elements that react – placed on left side of the equation
- Products – compounds/elements that are produced
  – placed on right side of the equation
- An arrow shows the direction of the reaction, left to right (though $\leftrightarrow$ is used to show reactions that can go in both directions).

Chemical reactions are characterized by the rearrangement of atoms when **reactants** are transformed into **products.**

$$C + O_2 \longrightarrow CO$$

reactants **product**

This is an example of a **combustion reaction**

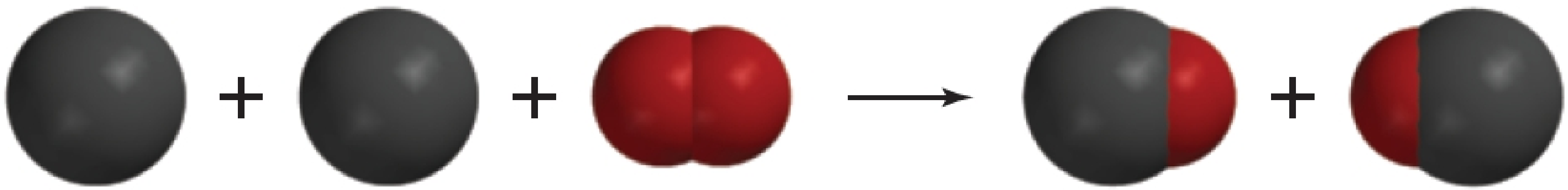
But the number of atoms on each side of the arrow must be equal (**Law of Conservation of Mass**).

$$\underbrace{2\,C + O_2}_{\substack{\text{2 carbon atoms} \\ \text{2 oxygen atoms}}} \longrightarrow \underbrace{2\,CO}_{\substack{\text{two carbon atoms} \\ \text{two oxygen atoms}}} \quad \text{(balanced)}$$

Chemical Equations

- Shows the reactants, products, and other information about the reaction:
  - Phases – solid, liquid, gas, aqueous, …
  - Reaction conditions – temperature, pressure catalysts, … (placed above/below the arrow)
- The equation must be balanced to conserve mass – the initial and final mass must be the same

$$2\,C \quad + \quad O_2 \longrightarrow 2\,CO$$



Another look, pictorially – using space-filling models

Balancing Equations

- Write proper formulas – DO NOT CHANGE THESE WHEN BALANCING
  - For elements in standard state, use chem. symbols
    - Except for diatomic gases:
      - H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2 exist as diatomic molecules in their standard states
      - These seven gases are H_2 + "7"

24 — Atomic number
Cr
52.00 — Atomic mass

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
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** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
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
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	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** (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** (264)	108 **Hs** (269)	109 **Mt** (268)	110	111	112	(113)	(114)	(115)	(116)	(117)	(118)

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Metals

Metalloids

Nonmetals

The 1–18 group designation has been recommended by the International Union of Pure and Applied Chemistry (IUPAC) but is not yet in wide use. In this text we use the standard U.S. notation for group numbers (1A–8A and 1B–8B). No names have been assigned for elements 110–112. Elements 113–118 have not yet been synthesized.
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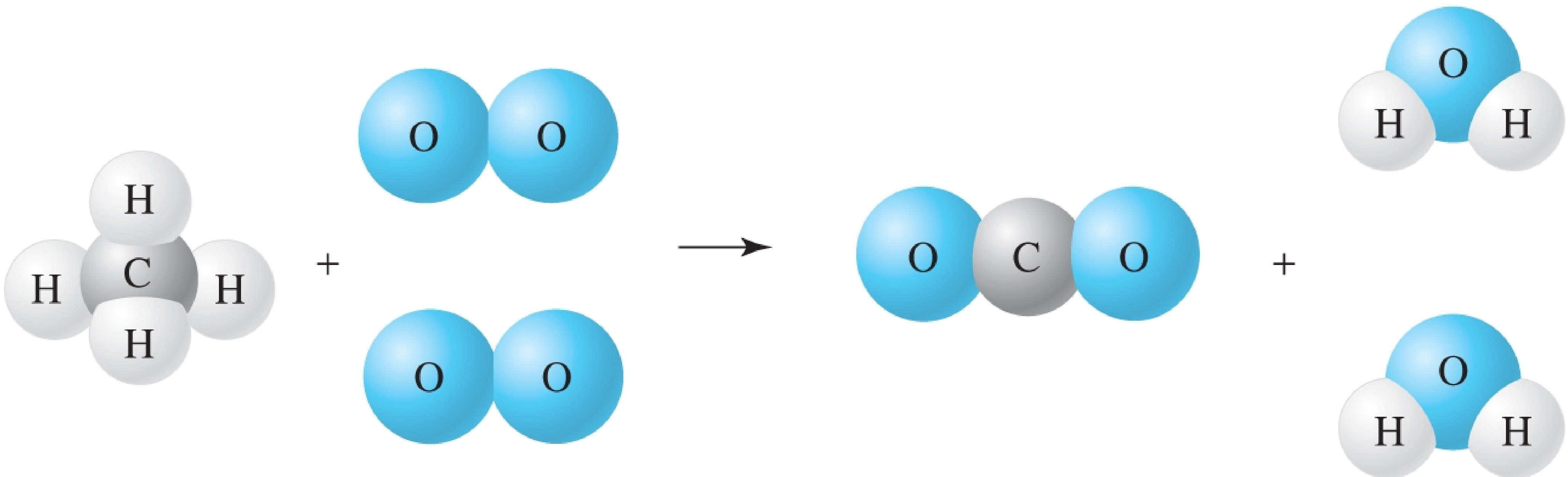

H
H
C
H
H
+
O
O
O
O
O
C
O
+
O
H
H
O
H
H

Balancing Equations

- Place coefficients in **<u>front</u>** of each element/compound to balance one **<u>element</u>** at a time.
  - Start with an element that is in only **<u>two</u>** compounds
  - Next balance elements that are in only **<u>one</u>** unknown (compounds without coefficients yet)
  - Usually balance free elements last
  - Often, polyatomic ions may be treated as a unit
- Remember that the coefficient applies to the entire compound, and subscripts only to one atom or polyatomic ion

Coefficient (affects both the H and O)

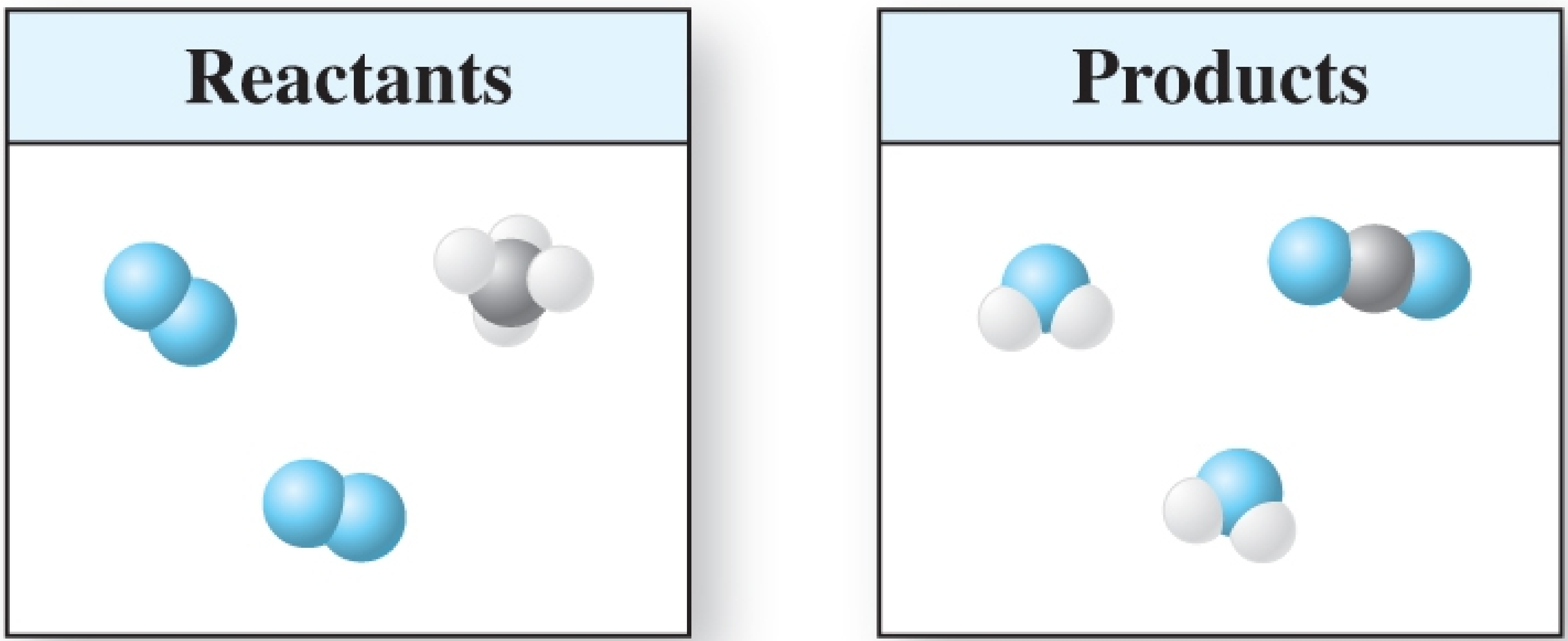
$2\,H_2O$

Subscript (affects only H)

Balancing Equations

- Continue until all compounds are balanced
- Reduce coefficients to lowest whole #s
  - Treat like an algebraic expression, and multiply all coefficients by the same value to reduce them or get rid of fractions
- Double check that all elements are balanced
- Double check that the total charge is the same on both sides of the equation (conservation of charge/electrons)

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$



Phases of chemicals

- Phases are shown by abbreviations in parenthesis after each chemical

  H_2O (s), H_2O (l), H_2O (g)

- Standard phases are:
  - (s) – solid
  - (l) – liquid
  - (g) – gas
  - (aq) – aqueous – dissolved in water
  - (↑) – gas produced from aqueous phase
  - (↓) – solid produced from aqueous phase

Types of Reactions

- Synthesis – compound formed from its base elements:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

- Decomposition – compound decomposes into its base elements:

$$2NH_3 \rightarrow N_2 + 3H_2$$

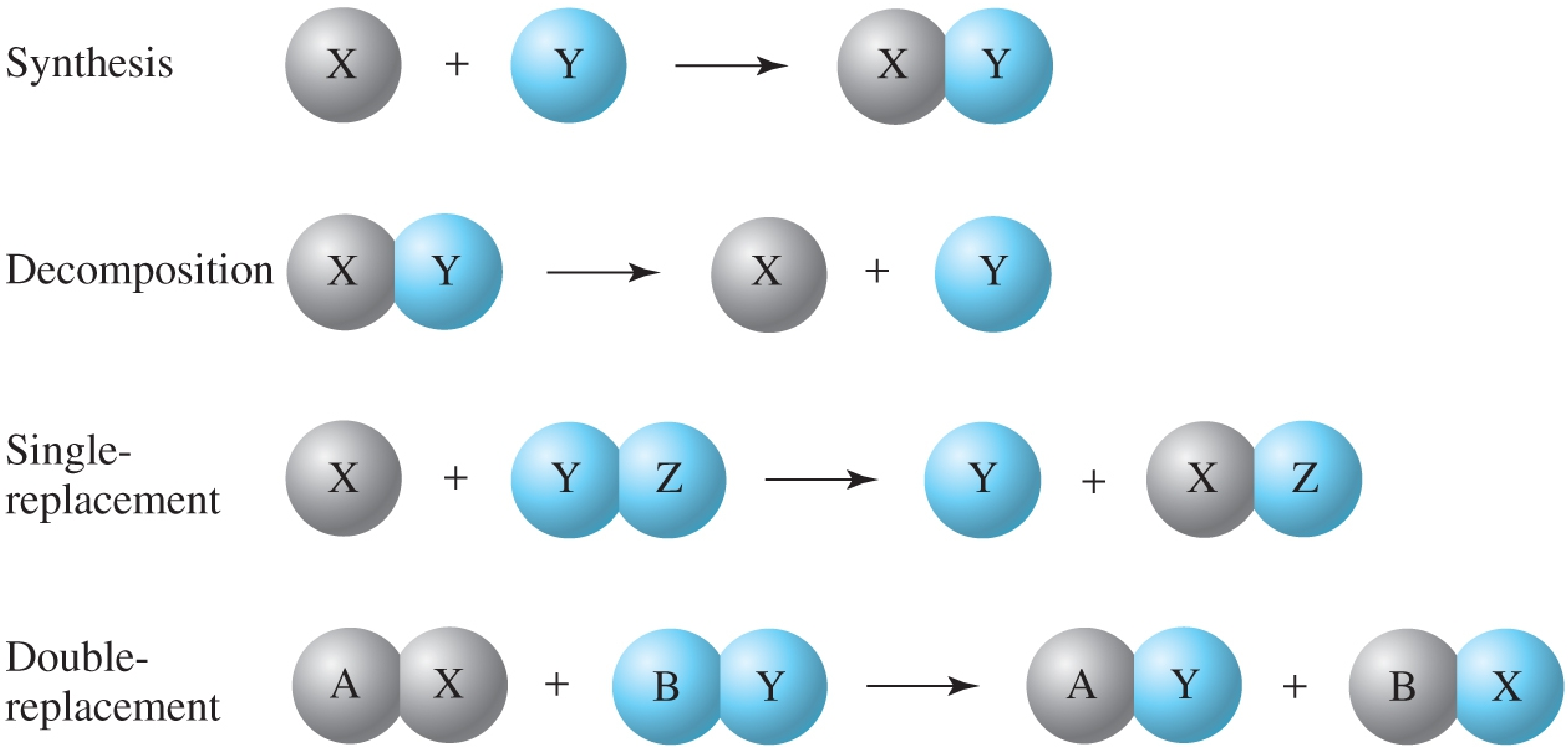
Types of Reactions

- Single replacement – an element replaces another in a compound:

$$2NaBr + I_2 \rightarrow 2NaI + Br_2$$

- Double replacement – two elements or polyatomic ions in two separate compounds switch places:

$$KNO_3 + Ca(OH)_2 \rightarrow KOH + Ca(NO_3)_2$$


Synthesis
X + Y → X Y
Decomposition
X Y → X + Y
Single-replacement
X + Y Z → Y + X Z
Double-replacement
A X + B Y → A Y + B X

Types of Reactions

- Complete combustion – fuel and oxygen produce water and carbon dioxide:

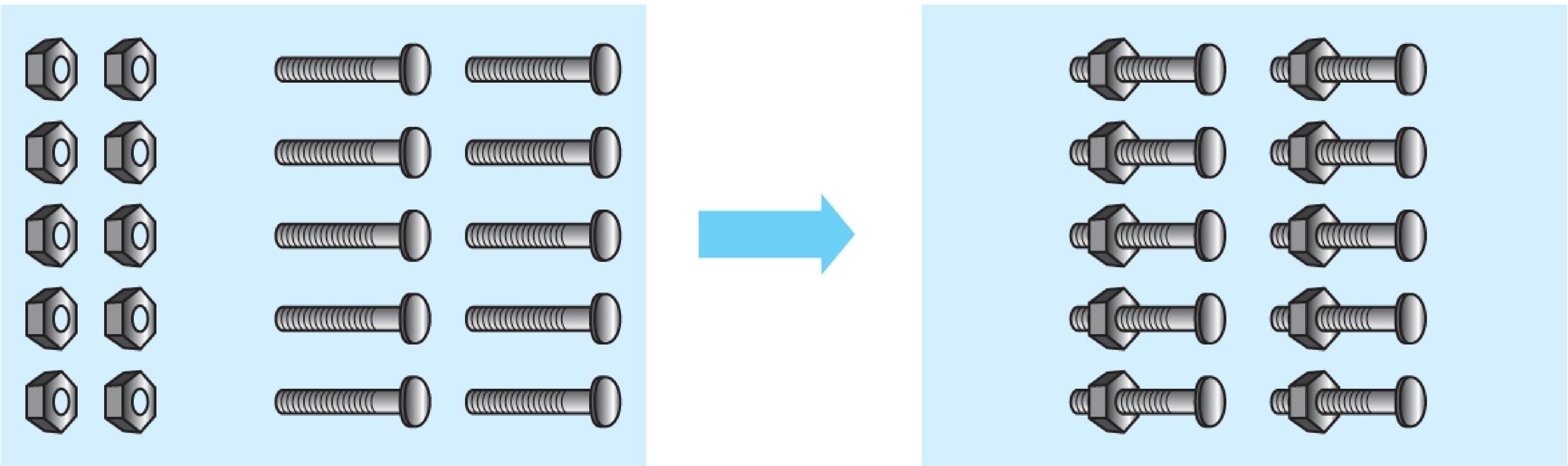
$$CH_4 + O_2 \rightarrow H_2O + CO_2$$

- Incomplete combustion – fuel and oxygen produce water and carbon Monoxide:

$$CH_4 + O_2 \rightarrow H_2O + CO$$

Stoichiometry

- The coefficients of a balanced equation relate the moles (numbers) of any compound to the moles (numbers) of any other compound in the equation.
- These molar ratios are used to 'convert' between any two compounds, whether they are reactants or products.
- This allows us to calculate moles of reactants needed, or products produced.



10 nuts + 10 bolts

10 one-nut, one-bolt combinations

(a)

$$2K \quad + \quad S \quad \rightarrow \quad K_2S$$

$$K \quad K \quad + \quad S \quad \rightarrow \quad K_2S$$

2 atoms of K react with 1 atom of S to produce 1 formula unit of K_2S

this also means that:

2 moles of K react with 1 mole of S to produce 1 mole of K_2S

Stoichiometry

- To perform stoichiometric calculations:
  - Write properly balanced equation
  - Convert all masses to moles
  - Use given amount and use molar ratio to:
    - cancel out original units
    - result in desired units
  - Convert final moles to mass, if needed

24 — Atomic number
Cr
52.00 — Atomic mass

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
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Limiting Reactants

- If the moles of the reactants exactly matches the molar ratio, then both reactants are completely consumed.
- Otherwise, one of the reactants is only partially consumed.
- The reactant that is used up is called the limiting reactant, since it is the one that stops the reaction.

$$2K \quad + \quad S \quad \rightarrow \quad K_2S$$

$$K \quad K \quad + \quad S \quad \rightarrow \quad K_2S$$

2 atoms of K react with 1 atom of S to produce 1 formula unit of K_2S

Here we have the exact amounts of each reactant needed to produce 1 formula unit of K_2S

$$2K \quad + \quad S \quad \rightarrow \quad K_2S$$

$$K \; K \; K \; K \quad + \quad S \quad \rightarrow \quad K_2S$$

Here the potassium is in excess,
so some is left unreacted.

The reaction stops when the sulfur is consumed, so <u>sulfur</u> is the limiting reactant.

$$2K \quad + \quad S \quad \rightarrow \quad K_2S$$

$$K \quad K \quad + \quad S \quad S \quad S \quad S \quad \rightarrow \quad K_2S$$

Here the sulfur is in excess,
so some is left unreacted.

The reaction stops when the potassium is consumed,
so in this case <u>potassium</u> is the limiting reactant.

Limiting Reactants

- To determine the limiting reactant:
  - Balance the equation
  - Convert any masses to moles
  - Select one product, and then calculate how much of that product each reactant could produce if it reacts completely
  - The reactant that would produce the least amount of the product is the limiting reactant
- Use this reactant for all stoichiometric calculations.