Chemical Equations

The “sentences” of Chemistry

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Chemical Equations

- Are a short-hand way of representing what happens in a chemical reaction
- Must obey the Law of Conservation of Mass

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Short-hand

- We could always state chemical reactions as:
  - Two moles of hydrogen gas react with one mole of oxygen gas to produce two moles of liquid water.
- Or we can be more succinct:
  - $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (l)$
- The second of these two is easier to read and know what is happening.

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Obey the Law of Conservation of Mass

- All chemical equations must be balanced, which means that the same number of each atom must be on both sides of the arrow.
- Examples:
  - $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (l)$ Balanced
  - $CH_4\ (g) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (l)$ not balanced!

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Chemical Equations

- The arrow (→) indicates the direction of the reaction.
- Substances to the left of the arrow are ***reactants***, substances to the right are ***products***.
- The plus sign (+) can be read as “and”.
- Other symbols are used to indicate the phase of the reactants or products.

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Other Symbols

- (*s*) indicates solid state
- (*l*) indicates liquid state
- (*g*) indicates gaseous state or vapor
- (*aq*) indicates aqueous or dissolved in water
- Δ indicates heating
- ↓ indicates a solid (precipitate) is formed
- ↑ indicates a gas is produced

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Balancing equations

- Equations can be balanced "by inspection," which means looking to see what needs to be added where.
- They can also be balanced by a mathematical method.
- We must remember that we cannot change the formulas of the compounds present in the reaction.

Balancing by inspection

- Example:
  - o CH_4 (*g*) + O_2 (*g*) → CO_2 (*g*) + H_2O (*l*)
- Looking at this we see that the carbons are balanced.
- Hydrogens are not. We have 4 on the left and 2 on the right. We need 2 more on the right. What times 2 is 4? "2"
  - o CH_4 (*g*) + O_2 (*g*) → CO_2 (*g*) + 2 H_2O (*l*)

CH_4 (*g*) + O_2 (*g*) → CO_2 (*g*) + 2 H_2O (*l*)

- Next we look at the oxygens. There are 2 on the left and 4 on the right. We need two more so we put a 2 in front of the O_2.
  - o CH_4 (*g*) + 2 O_2 (*g*) → CO_2 (*g*) + 2 H_2O (*l*)
- Now the equation is balanced.

Mathematical balancing

- This will work for all of the reactions you will have to balance in this class.
- It works by setting up a series of equations, one for each element present.
- We then "solve" the series so that all the element's equations work. This is done by choosing one value and calculating the rest.

CH_4 (*g*) + O_2 (*g*) → CO_2 (*g*) + H_2O (*l*)

- Write the equation with generic coefficients:
  - o a CH_4 (*g*) + b O_2 (*g*) → c CO_2 (*g*) + d H_2O (*l*)
- Write an equation for each element:
  - o C: a = c
  - o H 4a = 2d
  - o O 2b = 2c + d
- Choose a value for one of the "variables."
  - o a = 1
- Solve for the rest of the coefficients.

a = 1

- If a = 1, then c = 1.
- If a = 1, then 4a = 2d, d = 2a, d = 2
- If c = 1 and d = 2, then:
  - o 2b = 2c + d = 2(1) + 2 = 4, b = 2
- Therefore the balanced equation is:
  - o CH_4 (*g*) + 2 O_2 (*g*) → CO_2 (*g*) + 2 H_2O (*l*)
- This is the same as we got by inspection, and it should be.

Types of Reactions

- Synthesis reaction
  - o Two or more substances make one substance
    - $A + B \rightarrow C$
    - $4 Fe + 3 O_2 \rightarrow 2 Fe_2O_3$
- Decomposition reaction
  - o One substance breaks down into two or more substances
    - $A \rightarrow B + C$
    - $2 KClO_3 \rightarrow 2 KCl + 3 O_2$

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Types of reactions

- Single replacement reaction
  - o One atom replaces another
    - $A + BC \rightarrow B + AC$
    - $Fe + Ag_2SO_4 \rightarrow 2 Ag + FeSO_4$
- Double replacement reaction
  - o Also called metathesis, ionic compounds switch partners
    - $AB + CD \rightarrow AD + CB$
    - $3 KNO_3 + FeCl_3 \rightarrow Fe(NO_3)_3 + 3 KCl$
  - o Fred-Wilma + Barney-Betty → Fred-Betty + Barney-Wilma

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Types of Reactions

- Combustion reactions
  - o Reactions with Oxygen (O_2)
  - o Compounds containing C and H or C, H and O will always produce carbon dioxide and water as products in combustion reactions.
  - o $C_2H_5OH + 3 O_2 \rightarrow 2 CO_2 + 3 H_2O$
  - o $C_4H_8 + 6 O_2 \rightarrow 4 CO_2 + 4 H_2O$

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Chemical Equations in Calculations

- Chemical equations allow us to perform chemical calculations
- The equation will give us a series of conversion factors to be used in the calculation
- ***You must have a balanced chemical equation to do the calculation correctly***

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Conversion factors

- The stoichiometric coefficients (the numbers in the equation) are what we use as our conversion factors.
- Example:
  - o $2 C_4H_{10} + 13 O_2 \rightarrow 8 CO_2 + 10 H_2O$
  - o Some of the conversion factors we get are:

$$\frac{2 \text{ mol } C_4H_{10}}{10 \text{ mol } H_2O} \quad \frac{8 \text{ mol } CO_2}{2 \text{ mol } C_4H_{10}} \quad \frac{8 \text{ mol } CO_2}{13 \text{ mol } O_2}$$

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How to use the conversion

- Just like any other conversion factor.
- They can be used in either orientation.
- Using the previous equation, How many moles of Carbon Dioxide can be produced from 0.456 mol of Butane?
  - o $2 C_4H_{10} + 13 O_2 \rightarrow 8 CO_2 + 10 H_2O$

$$? \text{ mol } CO_2 = 0.456 \text{ mol } C_4H_{10} \times \frac{8 \text{ mol } CO_2}{2 \text{ mol } C_4H_{10}} = 1.82 \text{ mol } CO_2$$

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Don't measure moles!

- This is fine except that we don't measure moles, we measure mass, or grams.
- To do this kind of problem follow the path:
  - o $g\ A \Rightarrow mol\ A \Rightarrow mol\ B \Rightarrow g\ B$

Molar mass — Mole-to-mole conversion — Molar mass

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Example problem

- Chromium metal reacts with nitrogen gas to produce Chromium(II) Nitride. How many grams of Chromium(II) Nitride will be produced from 15.00 g of Chromium Metal?
  - o Solution:
  - o $3\ Cr + N_2 \rightarrow Cr_3N_2$

$$?\ g\ Cr_3N_2 = 15.00\ g\ Cr \times \frac{1\ mol\ Cr}{51.996\ g\ Cr} \times \frac{1\ mol\ Cr_3N_2}{3\ mol\ Cr} \times \frac{184.001\ g\ Cr_3N_2}{1\ mol\ Cr_3N_2}$$

$$= 17.69\ g\ Cr_3N_2$$

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More advanced chemical calculations

Given amounts of more than one reactant…

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Concept of Limiting Reactant

- Think of making cheese sandwiches
  - o You have 10 pieces of bread and 9 pieces of cheese. You can only make complete sandwiches.
    - If you use one piece of cheese per sandwich, you can make 5 sandwiches with 4 pieces of cheese left over. The bread is the limiting reactant.
    - If you use 3 pieces of cheese per sandwich, you can make 3 sandwiches with 4 pieces of bread left over. The cheese is the limiting reactant now.

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How does this apply to chemistry

- Look at a chemical reaction:
  - o $2\ H_2 + O_2 \rightarrow 2\ H_2O$
- Here, we use two moles of hydrogen for every mole of oxygen. If we only have 1.8 moles of H_2 for every mole of O_2, we'll run out of hydrogen before oxygen. Hydrogen will be the limiting reactant.

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How do we find the limiting reactant

- Calculate the mass of product from each reactant. The least mass will come from the limiting reactant.
- Example:
  - o 17.56 g of Ethanol (C_2H_6O) reacts with 34.17 g of Oxygen to produce Carbon Dioxide and water. What is the limiting reactant?

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Solution

- Write the balanced chemical equation:
  - $C_2H_6O + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$
- Setup each calculation:

$$?\ g\ CO_2 = 17.56\ g\ C_2H_6O \times \frac{1\ mol\ C_2H_6O}{46.08\ g\ C_2H_6O} \times \frac{2\ mol\ CO_2}{1\ mol\ C_2H_6O} \times \frac{44.01\ g\ CO_2}{1\ mol\ CO_2} = 33.54\ g\ CO_2$$

$$?\ g\ CO_2 = 34.17\ g\ O_2 \times \frac{1\ mol\ O_2}{32.00\ g\ O_2} \times \frac{2\ mol\ CO_2}{3\ mol\ O_2} \times \frac{44.01\ g\ CO_2}{1\ mol\ CO_2} = 31.32\ g\ CO_2$$

- Because the ethanol gives the least mass of CO_2, oxygen is the limiting reactant.

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Theoretical yields

- When we do the previous calculation, we must calculate both for the same product. The mass of product calculated is the theoretical yield of that reaction.
- The ***theoretical yield*** is the theoretical maximum amount of product made in a reaction. The real amount may be less than this. The real amount is the ***actual yield***.

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Percent Yield

- Percent yield is defined as: $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100$
- Scientists use percent yields because it's independent of the starting amount of materials.

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