CHE 1031: General Chemistry I

4. Stoichiometry of chemical reactions

4.1: Writing & balancing chemical equations

4.2: Classifying chemical reactions

4.3: Reaction stoichiometry

4.4: Reaction yields

4.5: Quantitative chemical analysis

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4. Stoichiometry of chemical reactions

4.1: Writing & balancing chemical equations

- Derive chemical equations from narrative descriptions of chemical reactions
- Write & balance chemical equations in molecular (complete), total ionic & ionic formats

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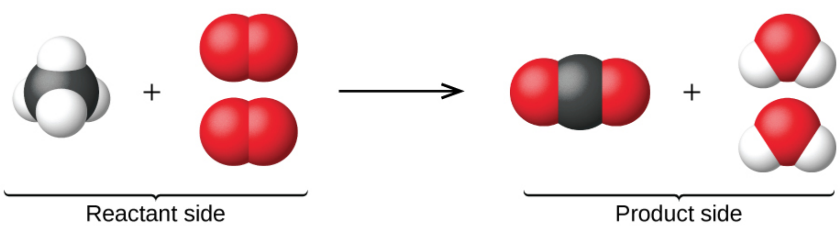
Chemical equations

Reaction: one methane molecule reacts with two oxygen gas molecules to yield one carbon dioxide molecules and two water molecules.

- Or 1 mole + 2 moles becomes 1 mole + 2 moles
- *Note that mass is conserved.*

combustion reaction

$$\overbrace{CH_4}^{\text{Reactant}} + \overbrace{\overbrace{2}^{\text{Coefficient}}O_2}^{\text{Reactant}} \xrightarrow[\text{change}]{} \overbrace{CO_2}^{\text{Product}} + \overbrace{\overbrace{2}^{\text{Coefficient}}H_2O}^{\text{Product}}$$



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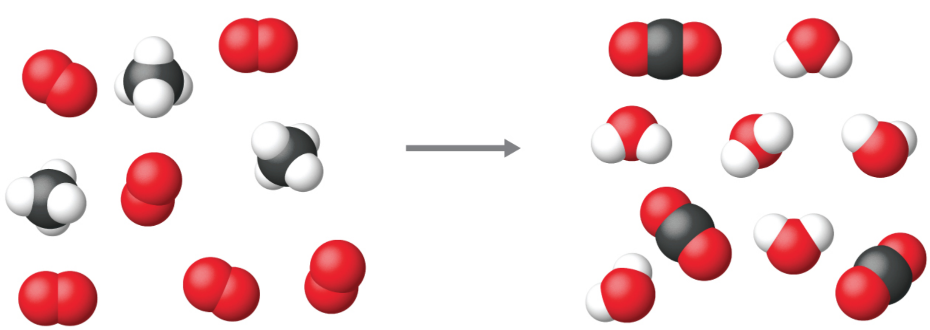
Ratios are constant, amounts differ

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

Mixture before reaction

Mixture after reaction



Critical point:

Coefficients of balanced equations are counting units NOT mass.

atoms
molecules
moles

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Balancing equations

Chemical equations are **balanced** because the same number and type of atoms are found on both sides of the equation.

- Thus, equations obey the law of conservation of mass.
- **Stoichiometric coefficients** are used to balance equations.

Only coefficients may be changed to balance equations.

- Subscripts cannot be changed because that would change chemical identity.

Electrolysis (addition of electricity) decomposes water into hydrogen & oxygen gases. *Balance this equation:*

$$\mathbf{2}\ H_2O \rightarrow \mathbf{2}\ H_2 + O_2$$

decomposition reaction

- H is balanced (2 atoms each side) but oxygen is not.
- Add a 2 coefficient to H2O to balance oxygen.
- But this unbalances H.
- Add a coefficient 2 to hydrogen gas to fix that. Check? Voila!

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Try these

Nitrogen and oxygen gas combine to form dinitrogen pentoxide.
(a) Use formulas to create a chemical equation.
(b) Add coefficients to balance the equation.

1

$$\underline{2}N_2 + \underline{5}O_2 \rightarrow \underline{2}N_2O_5$$

synthesis (combination) reaction

Ammonium nitrate decomposes to form nitrogen and oxygen gases and water.
(a) Use formulas to create a chemical equation.
(b) Add coefficients to balance the equation.

2

$$(NH_4)(NO_3) \rightarrow N_2 + O_2 + \underline{2}H_2O$$

$$\underline{2}(NH_4)(NO_3) \rightarrow \underline{2}N_2 + O_2 + \underline{4}H_2O$$

decomposition reaction

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Fractional coefficients (mainly for O_2)

Ethane (C_2H_6) is combusted.

C_2H_6 + $\underline{7/\cancel{2}}\, O_{\cancel{2}}$ → $\underline{2}$ CO_2 + $\underline{3}$ H_2O

7 O atoms *7 O atoms*

When balancing combustion reactions start with C, then H & save O for last.

$2C_2H_6$ + $7O_2$ → $4CO_2$ + $6H_2O$

Multiply through by 2 to remove the fraction.

combustion reaction

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Try this

Hexane (C_6H_{14}) is combusted.
Write a balanced chemical equation.

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C_6H_{14} + $\underline{19/2}$ O_2 → $\underline{6}$ CO_2 + $\underline{7}$ H_2O

$2C_6H_{14}$ + $19O_2$ → $12CO_2$ + $14H_2O$

combustion reaction

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Noting physical state

Chemical reactions often include notation of the physical states or reactants or products:

(s) *solid*
(l) *liquid (water, Hg)*
(g) *gas*
(aq) *aqueous solution*

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

displacement
redox
reaction

$CaCO_3(s) \xrightarrow[\Delta]{} CaO(s) + CO_2(g)$

heat added

decomposition
reaction

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Exchange reactions / dissociation

So far, we've written **molecular** chemical equations:

$CaCl_2(aq) + 2Ag(NO_3)(aq) \rightarrow Ca(NO_3)_2(aq) + 2AgCl(s)$

This is an **exchange reaction** in which two ionic compounds exchange ionic partners to create two new compounds.

- Predict new products (inner-inner, outer-outer).
- Metal first in new formulas
- Balance compounds for net charges of zero with subscripts.
- Add coefficients to balance the equation.

The ionic compounds in aqueous solutions **dissociate:** *come apart into ions.*

- So, show dissociation in chemical reactions.

$Ca^{+2} + 2Cl^{-1} + 2Ag^{+1} + 2NO_3^{-1} \rightarrow Ca^{+2} + 2NO_3^{-1} + 2AgCl(s)$

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Try this

Predict the products & balance this exchange reaction:

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$K_2S\ (aq) + Mg_3N_2(aq) \rightarrow$

exchange reaction
(double displacement)

- Predict new products (inner-inner, outer-outer).
- Metal first.
- Balance compounds for net charges of zero with subscripts.
  - Don't carry subscripts but use charges to create subscripts
- Add coefficients to balance the equation.

$K_2S\ (aq) + Mg_3N_2(aq) \rightarrow K\ N + Mg\ S$

$K_2S\ (aq) + Mg_3N_2(aq) \rightarrow K^{+1}\ N^{-3} + Mg^{+2}\ S^{-2}$

$K_2S\ (aq) + Mg_3N_2(aq) \rightarrow K^{+1}{}_3\ N^{-3} + Mg^{+2}\ S^{-2}$

$3K_2S\ (aq) + Mg_3N_2(aq) \rightarrow 2K^{+1}{}_3N^{-3} + 3Mg^{+2}S^{-2}$

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Dissociation to ionic equations

The ionic compounds in aqueous solutions **dissociate:** *come apart into ions.*

$CaCl_2(aq) + 2Ag(NO_3)(aq) \rightarrow Ca(NO_3)_2(aq) + 2AgCl(s)$

$Ca^{+2} + 2Cl^{-1} + 2Ag^{+1} + 2NO_3^{-1} \rightarrow Ca^{+2} + 2NO_3^{-1} + 2AgCl(s)$

exchange reaction
(double dis)

Notice that:

- the **solid** doesn't dissociate;&
- ionic subscripts become stoichiometric coefficients.

Now, cancel **spectator ions:** *ions present in the same form on both sides of the chemical equation.*

- What's left is the **net ionic equation**, showing actual chemical change; change of chemical identity.

$\cancel{Ca^{+2}} + 2Cl^{-1} + 2Ag^{+1} + \cancel{2NO_3^{-1}} \rightarrow \cancel{Ca^{+2}} + \cancel{2NO_3^{-1}} + 2AgCl(s)$

$2Cl^{-1} + 2Ag^{+1} \rightarrow 2AgCl(s)$

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Try this

When carbon dioxide gas is dissolved into aqueous sodium hydroxide, aqueous sodium carbonate and liquid water are produced.
(a) Write a balanced chemical equation.
(b) Write complete & net ionic equations.

5

exchange reaction **(double dis)**

$CO_2(g) + 2Na(OH)(aq) \rightarrow Na_2(CO_3)(aq) + H_2O(l)$ balanced

$CO_2(g) + 2Na^{+1} + 2(OH)^{-1} \rightarrow 2Na^{+1} + (CO_3)^{-2} + H_2O(l)$ complete ionic

$CO_2(g) + \cancel{2Na^{+1}} + 2(OH)^{-1} \rightarrow \cancel{2Na^{+1}} + (CO_3)^{-2} + H_2O(l)$ spectators

$CO_2(g) + 2(OH)^{-1} \rightarrow (CO_3)^{-2} + H_2O(l)$ net ionic

Notice that there are types of compounds that **don't dissociate:**

1. solids (s; aka precipitates; ppt; 🡻)
2. gases (g)
3. pure liquids (l; mainly water)

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One more

Diatomic chlorine and sodium hydroxide are mass produced by the electrolysis of brine; running electricity through salt water.
(a) Write a balanced chemical equation.
(b) Write complete & net ionic equations.

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$2NaCl(aq) + 2H_2O(l) \xrightarrow{e-} 2Na(OH)(aq) + H_2(g) + Cl_2(g)$

$\cancel{2Na^{+1}} + 2Cl^{-1} + 2H_2O(l) \rightarrow \cancel{2Na^{+1}} + 2(OH)^{-1} + H_2(g) + Cl_2(g)$

$2Cl^{-1} + 2H_2O(l) \rightarrow 2(OH)^{-1} + H_2(g) + Cl_2(g)$

redox reaction

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Can you?

(1) Recognize whether an chemical equation is balanced?

(2) Balance an unbalanced chemical equation?

(3) Write a chemical equation from a 'narrative' that uses the names of chemicals?

(4) Predict the products of an exchange reaction & complete a balanced chemical equation?

(5) Create complete ionic & net ionic equations from balanced chemical equations?

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4. Stoichiometry of chemical reactions

4.2: Classifying chemical reactions

- Define three common chemical reaction types:
  (1) precipitation; (2) neutralization; (3) redox
- Classify reactions given a balanced chemical equation
- Identify common acids & bases
- Predict solubility of common inorganic compounds using solubility rules
- Compute the oxidation states of elements in compounds

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Precipitation & solubility

Precipitation reaction: *two aqueous ionic solutions react via exchange to form two products; one product is a solid or **precipitate***

- Exchange, aka double displacement or double replacement

Examples**:** formation of coral reefs; mineralization of bone

Solubility: *the extent to which a compound can be dissolved in solvent like water; expressed in g/100 mL*

- **Insoluble** compounds are not soluble in water (solvent).

$$CaCl_2(aq) + Na_2(CO_3)(aq) \rightarrow 2NaCl(aq) + Ca(CO_3)(s)\downarrow$$

$$Ca^{+2} + \cancel{2Cl^{-1}} + \cancel{2Na^{+1}} + (CO_3)^{-2} \rightarrow \cancel{2Na^{+1}} + \cancel{2Cl^{-1}} + Ca(CO_3)(s)\downarrow$$

$$Ca^{+2} + (CO_3)^{-2} \rightarrow Ca(CO_3)(s)\downarrow$$

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Predicting precipitation & solubility?

s = ↓
aq = aqueous

Ions	Acetate	Bromide	Carbonate	Chlorate	Chloride	Fluoride	Hydrogen Carbonate	Hydroxide	Iodide	Nitrate	Nitrite	Phosphate	Sulfate	Sulfide	Sulfite
Aluminum	s	aq		aq	aq	s		s	—	aq		s	aq	—	
Ammonium	aq	aq	aq	aq	aq	aq	aq	—	aq	aq	aq	aq	aq	aq	aq
Barium	aq	aq	s	aq	aq	s		aq	aq	aq	aq	s	s	—	s
Calcium	aq	aq	s	aq	aq	s		s	aq	aq	aq	s	s	—	s
Cobalt(II)	aq	aq	s	aq	aq	—		s	aq	aq		s	aq	s	s
Copper(II)	aq	aq	s	aq	aq	aq		s		aq		s	aq	s	
Iron(II)	aq	aq	s		aq	s		s	aq	aq		s	aq	s	s
Iron(III)	—	aq			aq	s		s	aq	aq		s	aq	—	
Lead(II)	aq	s	s	aq	s	s		s	s	aq	aq	s	s	s	s
Lithium	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	s	aq	aq	aq
Magnesium	aq	aq	s	aq	aq	s		s	aq	aq	aq	s	aq	—	aq
Nickel	aq	aq	s	aq	aq	aq		s	aq	aq		s	aq	s	s
Potassium	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
Silver	s	s	s	aq	s	aq		—	s	aq	s	s	s	s	s
Sodium	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq	aq
Zinc	aq	aq	s	aq	aq	aq		s	aq	aq		s	aq	s	s

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Try this

What makes this bright yellow precipitate when aqueous solutions of potassium iodide and lead (II) nitrate are mixed?
(a) Write a balanced chemical equation.
(b) Write complete & net ionic equations.

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$KI(aq) + Pb(NO_3)_2(aq) \rightarrow$

$2KI(aq) + Pb(NO_3)_2(aq) \rightarrow$
$2K(NO_3)(aq) + PbI_2(s; ppt)\downarrow$

$\cancel{2K^{+1}} + 2I^{-1} + Pb^{+2} + \cancel{2(NO_3)^{-1}} \rightarrow$
$\cancel{2K^{+1}} + \cancel{2(NO_3)^{-1}} + PbI_2(s; ppt)\downarrow$

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One more

Which of these reactions will produce a precipitate?
Write complete ionic equations for those that do form ppt.

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(a) potassium sulfate + barium nitrate →
(b) lithium chloride + silver (I) acetate →
(c) lead (II) nitrate + ammonium carbonate →

(a) $\cancel{2K^{+1}} + (SO_4)^{-2} + Ba^{+2} + \cancel{2(NO_3)^{-1}} \rightarrow \cancel{2K^{+1}} + \cancel{2(NO_3)^{-1}} + Ba(SO_4)\downarrow$

(b) $\cancel{Li^{+1}} + Cl^{-1} + Ag^{+1} + \cancel{(C_2H_3O_2)^{-1}} \rightarrow \cancel{Li^{+1}} + \cancel{(C_2H_3O_2)^{-1}} + AgCl\downarrow$

(c) $Pb^{+2} + \cancel{2(NO_3)^{-1}} + \cancel{2(NH_4)^{+1}} + (CO_3)^{-1} \rightarrow Pb(CO_3)\downarrow + \cancel{2(NH_4)^{+1}} + \cancel{2(NO_3)^{-1}}$

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Acid-base reactions

Acid-base reactions (aka neutralizations)*: hydrogen ion(s) (H^{+1}) are transferred from one chemical to another*

- H^{+1} is transferred from acid to base

Examples: cleaning milking systems; central to all aquatic environments & the biochemistry of all living organisms on earth

Acid: compound that dissociates in water & produces hydronium ion, H_3O^{+1}

- Acid formulas (usually) begin with 'H'.

$HCl(aq)$ +	H_2O	$\rightarrow$	Cl^{-1}	+	H_3O^{+1}
acid	base		conjugate base		conjugate acid

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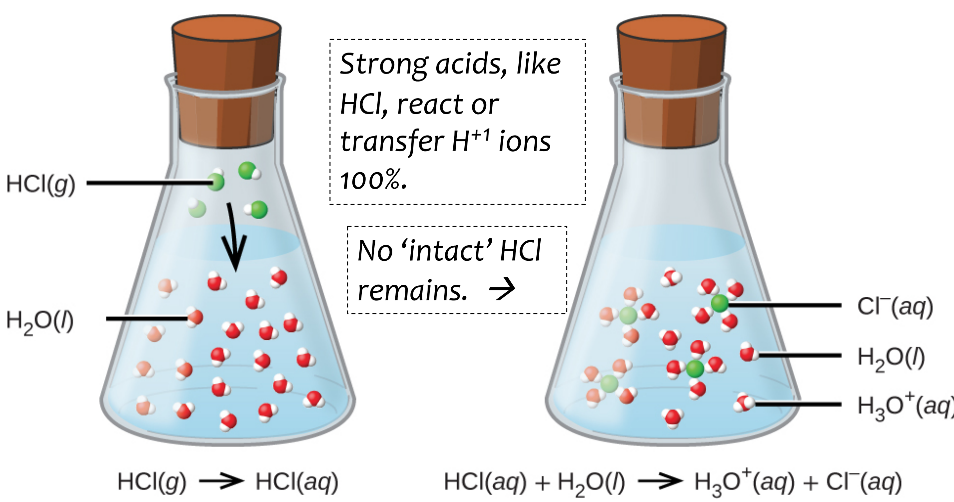
Strong acids → 100% dissociation

$$HCl(aq) + H_2O \rightarrow Cl^{-1} + H_3O^{+1}$$



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Weak acids → << 100% dissociation

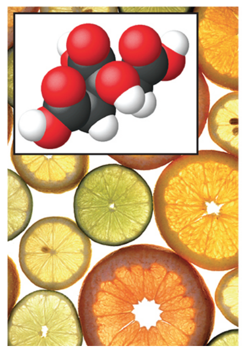
While strong acids complete dissociate & transfer 100% of their H^{+1} ions, **weak acids** lose only a small percentage of their H^{+1} ions.

Examples: in nature, common organic acids are weak

- Tangy fruit juice, sting of insect bites, vinegar, body odor

$$(CH_3COO_2)H(aq) + H_2O(l) \rightleftharpoons (CH_3CO_2)^{-1}(aq) + H_3O^{+1}(aq)$$

double arrow
indicates reversible,
weak acid, incomplete dissociation



- Only about 1% of acetic acid dissociates.
- Degree of dissociation differs for each weak acid.

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Strong vs. weak acids?

Learn these **seven strong acids**.
Acids not on the list are weak.

7 strong acids	
HBr	hydrobromic acid
HCl	hydrochloric acid
HI	hydroiodic acid
HNO_3	nitric acid
H_2SO_4	sulfuric acid
$HClO_3$	chloric acid
$HClO_4$	perchloric acid

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Bases

Bases: *compounds that accept hydrogen ions (H^{+1})*

- Most often compounds that dissociate OH^{-1} in water.
  - Ionic hydroxides are <u>strong bases</u>.
- But NH_3 (ammonia) can also accept H^{+1} ions.
  - Ammonia is a <u>weak base</u>.

$$Na(OH) \xrightarrow{\text{water}} Na^{+1} + OH^{-1}$$

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^{+1}(aq) + OH^{-1}(aq)$$

NH3 used as fertilizer

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NH3 as cleaner

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Neutralization reactions

Neutralizations reactions: *reaction of an acid & base to produce water & a salt.*

- Neutralization reactions are exchange reactions.

acid + base → water + salt

Any ionic compound

Philips Milk of Magnesia, antacids

$$Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$$

high pH base | low pH acid | neutral pH water

$$Mg(OH)_2(s) + 2H^{+1} + \cancel{2Cl^{-1}} \rightarrow Mg^{+2} + \cancel{2Cl^{-1}} + 2H_2O(l)$$

$$Mg(OH)_2(s) + 2H^{+1} \rightarrow Mg^{+2} + 2H_2O(l)$$

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Try these

The weak acid hydrogen hypochlorite reacts with water.
Write a balanced chemical equation.

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$H(ClO)(aq) + H_2O(l) \rightleftharpoons ClO^{-1}(aq) + H_3O^{+1}(aq)$

Reversible because
HClO is a weak acid.

A solution of barium hydroxide is neutralized with nitric acid.
(a) Write a balanced chemical equation.
(b) Write complete & net ionic equations.

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$Ba(OH)_2(aq) + 2H(NO_3)(aq) \rightarrow Ba(NO_3)_2(aq) + 2H_2O(l)$

$\cancel{Ba^{+2}} + 2(OH)^{-1} + 2H^{+1} + \cancel{2(NO_3)^{-1}} \rightarrow \cancel{Ba^{+2}} + \cancel{2(NO_3)^{-1}} + 2H_2O(l)$

Often the net ionic equation of acid-base: $H^{+1} + (OH)^{-1} \rightarrow H_2O$

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Reduction-oxidation reactions

Earth's atmosphere is 21% oxygen gas (O_2) & this gas is vital for life on earth. Many reactions involve O_2, and the term oxidation was originally used to describe these reactions.

Oxidation & reduction: *now are used to describe chemical reactions involving the transfer of electrons.*

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

Notice both elements go from uncharged (elemental) to charged ions.

Half-reactions show us what's happening to each reactant.

$2Na(s) \rightarrow 2Na^{+1} + 2e^-$ *Each Na(s) loses one e-.*

$Cl_2(g) + 2e^- \rightarrow 2Cl^{-1}$ *Each atom in Cl2(g) gains one e-.*

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Oxidation & reduction

Oxidation & reduction are linked & **must occur simultaneously.**

Oxidation: *loss of electron(s)*

- Metals are oxidized
- Become positively charged **cations.**
- Oxidation numbers increase.
- Oxidized elements are the **reducing agent.**

't' mimics + sign

Reduction: *gain of electron(s)*

- Nonmetals are reduced.
- Become negatively charged **anions.**
- Oxidation numbers are reduced.
- Reduced elements are the **oxidizing agent.**

an: a negative ion

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Oxidation numbers

So, how do you know which is oxidized and which is reduced?

Oxidation numbers (aka oxidation state)**:** *the charge an atom would possess if the compound were ionic*

- assigned on a per atom basis

Guidelines:

1. Elemental atoms or molecules = 0
2. Monoatomic ions = ionic charge
3. Common nonmetals:
   - H = +1 with nonmetals or = -1 with metals
   - O = -2 (except -1 in peroxide; + when with F)
   - halogens = -1
4. Oxidation numbers of ions sum to ionic charge & oxidation numbers of molecules sum to zero.

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Applying oxidation numbers

Assign oxidation numbers to all elements in these: 11

(a) H_2S
(b) SO_3^{-2}
(c) $Na_2(SO_4)$

Note that S & N have to most variable oxidation numbers.

(a)

H_2	S
+1	- 2
+2	-2 = 0

You don't know about S, but know that H is +1 x 2 = +2.
In order to sum to zero, S 'side' must be -2.
Since there is only one S atom, its oxidation number = -2.

(b)

(S	$O_3)^{-2}$
+4	- 2
+4	- 6 = -2

Here you know O is -2, so the sum of the O side is -6.
In order to sum to -2, S 'side' must be +4.
Since there is only one S atom, its oxidation number = +4.

(c)

Na_2	(S	$O_4)$
+1	+6	- 2
+2	+6	- 8

Here you know O is -2 & Na is +1.
In order to sum to zero, S 'side' must be +6.

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Try these

Assign oxidation numbers to all elements: 12

(a) $K(NO_3)$
(b) AlH_3
(c) NH_4^{+1}
(d) $H_2(PO_4)^{-1}$

Note that S & N have to most variable oxidation numbers.

(a)

K	(N	$O_3)$
+1	+5	- 2
+1	+5	-6 = 0

(c)

N	H_4^{+1}
-3	+1
-3	+4 = +1

(b)

Al	H_3
+3	- 1
+3	- 3 = 0

(d)

H_2	(P	$O_4)^{-1}$
+1	+5	-2
+2	+5	-8 = -1

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Redox reactions

If a chemical reaction is a redox reaction, the **oxidation numbers** of at least two elements **change** from reactants to products.

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

0 0 +1/-1

↑so ox

↓so red

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Solid rocket fuel is combusted by this reaction.

Assign oxidation numbers to see which element is oxidized & which reduced?

$$10Al(s) + 6(NH_4)(ClO_4)(s) \rightarrow 4Al_2O_3(s) + 2AlCl_3(s) + 12H_2O(g) + 3N_2(g)$$

0 -3/+1 +7/-2 +3/-2 +3/-1 +1/-2 0

↑so ox ↑so ox

↓so red

↑so ox

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Displacement reactions

Displacement reactions: *metals are oxidized by acids or salts*

$$Zn(s) + 2HCl(aq) \rightarrow H_2(g) + ZnCl_2$$

0 +1/-1 0 +2/-1

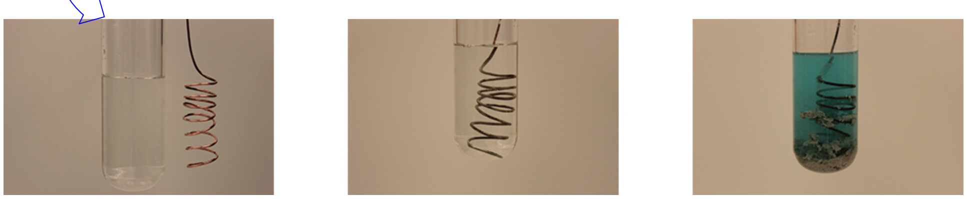
↑so ox

↓so red

$$Cu(s) + 2Ag(NO_3)(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

0 +1/+5/-2 +2/+5/-2 0

↑so ox ↓so red



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Try this

Assign oxidation numbers to identify redox reactions, & determine what's oxidized & what's reduced.

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(a) $Zn(CO_3)(s) \rightarrow ZnO(s) + CO_2(g)$
+2/+4/-2 +2/-2 +4/-2 not redox

(b) $2Ga(l) + 3Br_2(l) \rightarrow 2GaBr_3(s)$
0 0 +3/-1 redox

(c) $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
+1 /-1 +1/-2 0 redox [beware peroxide!]

(d) $BaCl_2(aq) + K_2(SO_4)(aq) \rightarrow Ba(SO_4)(s) + 2KCl(aq)$
+2 /-1 +1/+6/-2 +2/+6/-2 +1/-1 not redox

(e) $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$
-2/+1 0 +4/-2 +1/-2 redox

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Using half-equations to balance redox

When redox reactions occur in aqueous solutions, water, hydronium ion, and / or hydroxide ion may play non-redox roles in the reactions. Balancing redox equations with the **half-equation method** shows the participation of these aqueous reactants.

1. Separate the reaction into half-equations.
2. Balance all elements except O & H.
3. Balance O by adding one H_2O for every O needed.
4. Balance H by adding one H^{+1} for every H needed.
5. Balance charge by adding e- to the more positive side.
6. If needed, multiply by factors to add the same number of e- to both half-equations.
7. Add half-equations together, cancel spectators & simplify. *All added electrons should cancel.

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Let's try it

Write a balanced equation for this redox reaction in an aqueous acidic solution using the half-equation method: 15

$$Cr_2O_7^{-2} + Fe^{+2} \rightarrow Cr^{+3} + Fe^{+3}$$

Reduction		Step	Oxidation	
$Cr_2O_7^{-2} \rightarrow$	Cr^{+3}	1	$Fe^{+2} \rightarrow$	Fe^{+3}
$Cr_2O_7^{-2} \rightarrow$	$2Cr^{+3}$	2	$Fe^{+2} \rightarrow$	Fe^{+3}
$Cr_2O_7^{-2} \rightarrow$	$2Cr^{+3} + 7H_2O$	3	$Fe^{+2} \rightarrow$	Fe^{+3}
$Cr_2O_7^{-2} + 14H^{+1} \rightarrow$	$2Cr^{+3} + 7H_2O$	4	$Fe^{+2} \rightarrow$	Fe^{+3}
+12	+6		+2	+3
$Cr_2O_7^{-2} + 14H^{+1} + 6e^- \rightarrow$	$2Cr^{+3} + 7H_2O$	5	$Fe^{+2} \rightarrow$	$Fe^{+3} + 1e^-$
+6	+6		+2	+2
$Cr_2O_7^{-2} + 14H^{+1} + 6e^- \rightarrow$	$2Cr^{+3} + 7H_2O$	6	$6Fe^{+2} \rightarrow$	$6Fe^{+3} + 6e^-$

reduction: e- added to reactants

oxidation: e- added to products

$$Cr_2O_7^{-2} + 14H^{+1} + \cancel{6e^-} + 6Fe^{+2} \rightarrow 2Cr^{+3} + 7H_2O + 6Fe^{+3} + \cancel{6e^-}$$

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Another

Write a balanced equation for this redox reaction in an aqueous acidic solution using half-equations:

$$H_2O_2(aq) + 2H^{+1} + 2Fe^{+2} \rightarrow 2H_2O + 2Fe^{+3}$$

Let the water & acid find there way in as you solve the half-equations.

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Reduction		Step	Oxidation	
$H_2O_2 \rightarrow$	$2H_2O$	1	$2Fe^{+2} \rightarrow$	$2Fe^{+3}$
$H_2O_2 \rightarrow$	$2H_2O$	2	$2Fe^{+2} \rightarrow$	$2Fe^{+3}$
$H_2O_2 + 2H^{+1} \rightarrow$	$2H_2O$	3	$2Fe^{+2} \rightarrow$	$2Fe^{+3}$
$H_2O_2 + 2H^{+1} \rightarrow$	$2H_2O$	4	$2Fe^{+2} \rightarrow$	$2Fe^{+3}$
+2	0		+4	+6
$H_2O_2 + 2H^{+1} + 2e^- \rightarrow$	$2H_2O$	5	$2Fe^{+2} \rightarrow$	$2Fe^{+3} + 2e^-$
0	0		+4	+4
$H_2O_2 + 2H^{+1} + 2e^- \rightarrow$	$2H_2O$	6	$2Fe^{+2} \rightarrow$	$2Fe^{+3} + 2e^-$

reduction: e- added to reactants

oxidation: e- added to products

$$H_2O_2 + 2H^{+1} + \cancel{2e^-}\ 2Fe^{+2} \rightarrow 2H_2O\ 2Fe^{+3} + \cancel{2e^-}$$

7

38

Can you?

(1) Use the solubility chart to determine whether a reaction is a precipitation reaction?

(2) Define the terms acid and base & differentiate between strong and weak acids & bases?

(3) Recognize & complete an acid-base (aka neutralization) reaction?

(4) Assign oxidation numbers to elements in compounds?

(5) Recognize redox reactions & complete displacement reactions? Identify elements that are oxidized & reduced?

(6) Solve redox reactions in acidic aqueous solutions using the half-reaction method? Know what is oxidized & reduced?

39

4. Stoichiometry of chemical reactions

4.3: Reaction stoichiometry

- Explain the concept of stoichiometry as it pertains to chemical reactions
- Use balanced chemical equations to derive stoichiometric factors for reactants & products
- Perform stoichiometric calculations involving mass, moles & solution molarity

40

What is stoichiometry?

Stoichiometry: *the chemistry term for the ratio relationships between reactants & products*

- From the Greek: '*stoicheion*' *(element) and* '*metron*' *(measure)*

2 graham crackers + 2 chocolate bars + 1 marshmallow → 1 s'more

Camping with 6 friends and want 2 s'mores each?

- Need to make a dozen s'mores. What do you need to bring?
- *Use the balanced chemical equation to make stoichiometric conversion factors.*

$$\frac{12\ \cancel{\text{s'mores}}\quad 2\ \text{graham crackers}}{1\ \cancel{\text{s'more}}} = 24\ \text{graham crackers}$$

$$\frac{12\ \cancel{\text{s'mores}}\quad 2\ \text{chocolate bars}}{1\ \cancel{\text{s'more}}} = 24\ \text{chocolate bars}$$

$$\frac{12\ \cancel{\text{s'mores}}\quad 1\ \text{marshmallow}}{1\ \cancel{\text{s'more}}} = 12\ \text{marshmallows}$$

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The stoichiometry of chemical equations

The Haber-Bosch reaction is used to make ammonia from hydrogen & nitrogen gas:

$$N_2(g)\ +\ 3H_2(g) \rightarrow 2NH_3(g)$$

synthesis reaction

Use the balanced chemical equation to make all possible stoichiometric conversion factors.

$$\frac{1\ \text{mole}\ N_2}{3\ \text{moles}\ H_2} \qquad \frac{1\ \text{mole}\ N_2}{2\ \text{moles}\ NH_3} \qquad \frac{3\ \text{mole}\ H_2}{2\ \text{moles}\ NH_3}$$

How many moles of each diatomic gas would be needed to make 100 moles of ammonia?

17

$$\frac{100\ \cancel{\text{moles}\ NH_3}\quad 1\ \text{mole}\ N_2}{2\ \cancel{\text{moles}\ NH_3}} = 50\ \text{moles}\ N_2$$

$$\frac{100\ \cancel{\text{moles}\ NH_3}\quad 3\ \text{mole}\ H_2}{2\ \cancel{\text{moles}\ NH_3}} = 150\ \text{moles}\ H_2$$

42

So, try this

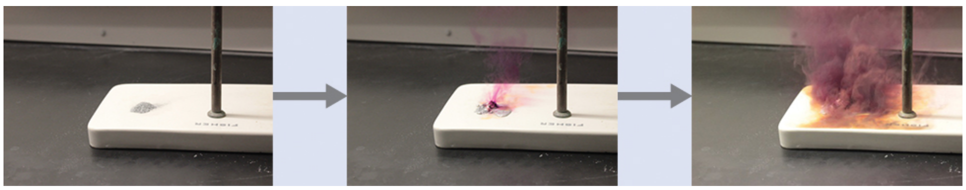
How many moles of I_2 are required to react with 0.429 mole of Al?

$$2Al(s) + 3I_2(s) \rightarrow 2AlI_3(s)$$

18

$$\frac{0.429\ \cancel{\text{mol Al}}\quad 3\ \text{mol } I_2}{\quad 2\ \cancel{\text{mol Al}}} = 0.644\ \text{mol } I_2 \qquad \text{mol } I_2$$

synthesis reaction



Al (s) + I_2(s)

Heat caused by the reaction turns some I_2 into purple I_2 gas.

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Mole map for chemical reactions?

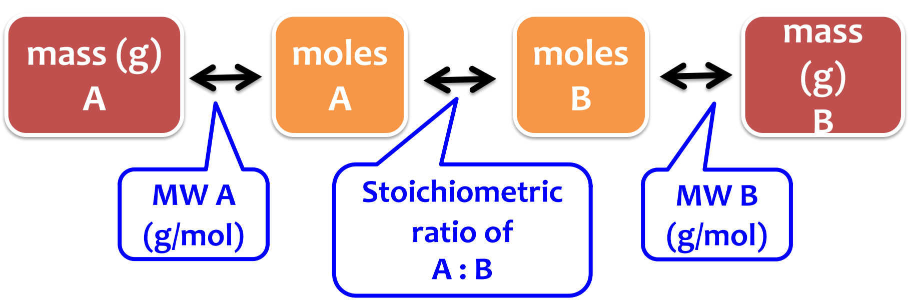
A **mole map** can help make use of this new stoichiometric conversion factor.

(1) To relate the amount of **reactant (A)** to **product (B)**.

(2) To relate the amount of **two reactants (A & B)** or products to one another.

1 $2A \rightarrow 5B$

2 $2A + 3B \rightarrow 4C + 5D$



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Using this mass-mole map

What mass of sodium hydroxide is required to produce 16 g of milk of magnesia, $Mg(OH)_2$?

$$MgCl_2(aq) + 2Na(OH)(aq) \rightarrow Mg(OH)_2(s) + 2NaCl(aq)$$

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Strategy: mass P → moles P → moles R → mass R

MW P — R:P ratio — MW R

exchange (double dis) reaction

$Mg(OH)_2$ = 58.30 g/mol

Na(OH) = 40.00 g/mol

$$\frac{16\ \cancel{g\ Mg(OH)_2}}{} \cdot \frac{1\ \cancel{mol\ Mg(OH)_2}}{58.30\ \cancel{g}} \cdot \frac{2\ \cancel{mol\ Na(OH)}}{1\ \cancel{mol\ Mg(OH)_2}} \cdot \frac{40.00\ g\ Na(OH)}{1\ \cancel{mol\ Na(OH)}}$$

= 22 g Na(OH)

45

Try this

What mass of oxygen gas is consumed when 702 g of octane are combusted?

20

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

Strategy: octane (g) → octane (mol) → O_2 (mol) → O_2 (g)

MW octane — O_2:octane ratio — MW O_2

combustion reaction

C_8H_{18} = 114.23 g/mol

O_2 = 31.98 g/mol

$$\frac{702\ \cancel{g\ C_8H_{18}}}{} \cdot \frac{1\ \cancel{mol\ C_8H_{18}}}{114.23\ \cancel{g}} \cdot \frac{25\ \cancel{mol\ O_2}}{2\ \cancel{mol\ C_8H_{18}}} \cdot \frac{31.98\ g\ O_2}{1\ \cancel{mol\ O_2}} = 2.46\ E3\ g\ O_2$$

46

Relating molecules to moles

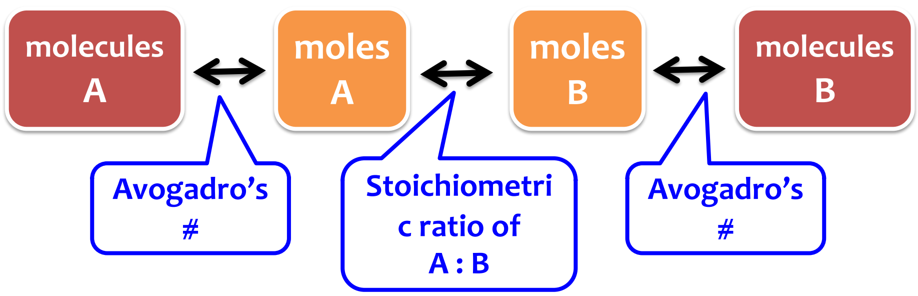
A **mole map** can help make use of this new stoichiometric conversion factor to numbers of molecules rather than mass.

(1) To relate the amount of **reactant (A)** to **product (B)**.

(2) To relate the amount of **two reactants (A & B)** or products to one another.

1 $2A \rightarrow 5B$

2 $2A + 3B \rightarrow 4C + 5D$



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Using the molecule-mole map

How many carbon dioxide molecules are produced when 0.75 mol of propane (C_3H_8) are combusted?

21

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Strategy: moles C_3H_8 → moles CO_2 → molecules CO_2

CO_2:C_3H_8 ratio

Av's #

combustion reaction

$$\frac{0.75\ \text{mol}\ \cancel{C_3H_8}}{} \times \frac{3\ \cancel{\text{mol}\ CO_2}}{1\ \cancel{\text{mol}\ C_3H_8}} \times \frac{6.02\ \text{E}23\ \text{molecules}\ CO_2}{1\ \cancel{\text{mol}\ CO_2}}$$

= 1.4 E24 molecules CO_2

48

Try this

How many NH_3 molecules are produced by the reaction of 2.4 E24 molecules of $Ca(OH)_2$?

22

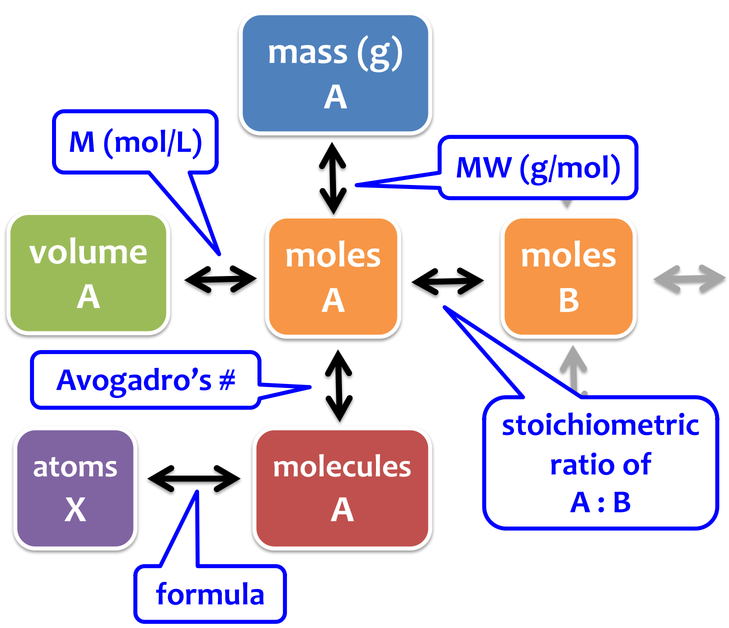
$$(NH_4)_2(SO_4) + Ca(OH)_2 \rightarrow 2NH_3 + Ca(SO_4) + 2H_2O$$

Strategy: molecules → moles → moles → molecules
$Ca(OH)_2$ $Ca(OH)_2$ NH_3 NH_3
Av's # $NH_3:Ca(OH)_2$ ratio Av's #

$$\frac{2.4\text{ E24 molec } \cancel{Ca(OH)_2}}{} \cdot \frac{1\text{ mol } \cancel{Ca(OH)_2}}{6.02\text{ E23 } \cancel{\text{molecules}}} \cdot \frac{2\text{ mol } \cancel{NH_3}}{1\text{ mol } \cancel{Ca(OH)_2}} \cdot \frac{6.02\text{ E23 molec } NH_3}{1\text{ } \cancel{\text{mol } NH_3}}$$

= 4.8 E24 molecules NH_3

Compiling a comprehensive mole map



Test the comprehensive map

A mass of ammonium sulfate that contains 3.14 E25 atoms of hydrogen is used to produce calcium sulfate. If the volume of the reaction is 2500 mL, what is the molar concentration of calcium sulfate?

23

$(NH_4)_2(SO_4) + Ca(OH)_2 \rightarrow 2NH_3 + Ca(SO_4) + 2H_2O$

Strategy: atoms H → molecules → moles → moles → M
-------$(NH_4)_2(SO_4)$-----   --$Ca(SO_4)$---

3.14 E25 ~~H atoms~~	1 ~~molec (NH…~~	1 ~~mol (NH…~~	1 mol Ca…	=
	8 ~~H atoms~~	6.02 E23 ~~molec (NH…~~	1 mol ~~(NH…~~	2.500 L Ca…

= 2.61 M $Ca(OH)_2$

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Can you?

(1) Create stoichiometric conversion factors from a balanced chemical equation?

(2) Use stoichiometric conversion factors to convert moles of reactant A to reactant B or to product P?

(3) Draw a mole-map that explains the use of these conversion factors?

- atomic or molar mass (MW)
- Avogadro's number
- molarity
- stoichiometric ratios

(4) Use that mole-map to solve quantitative problems?

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4. Stoichiometry of chemical reactions

4.4: Reaction yields

- Explain the concepts of theoretical yield & limiting reactants
- Derive the theoretical yield for a reaction under specified conditions
- Calculate the percent yield for a reaction

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Limiting reactants

Limiting reactant: *a reactant that is completely consumed by a reaction and dictates the amount of product produced*

Excess reactant: *a reactant that is <u>not</u> entirely consumed by a reaction; some excess reactant remains after the reaction occurs*

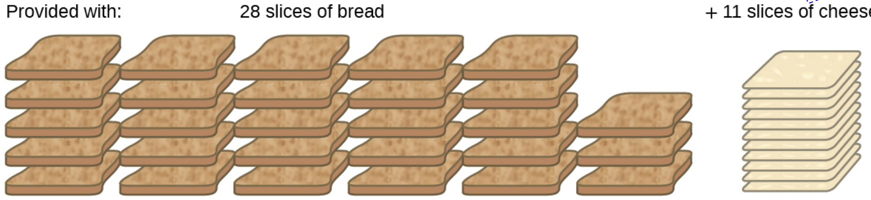
Theoretical yield: *the amount of product that can be made given the amount of limiting reactant available; <u>dependent on l.r.</u>*

2 breads + 1 cheese → 1 grilled cheese sandwich

$2B + C \rightarrow B_2C$

synthesis reaction

Provided with: 28 slices of bread + 11 slices of cheese



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Limiting reactants

Limiting reactant: *a reactant that is completely consumed by a reaction and dictates the amount of product produced*

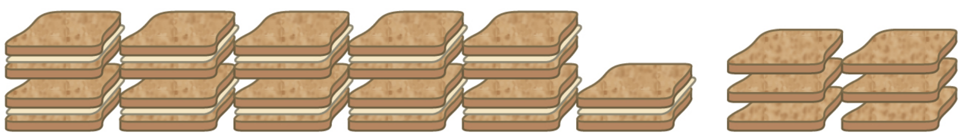
Excess reactant: *a reactant that is not entirely consumed by a reaction; some excess reactant remains after the reaction occurs*

Theoretical yield: *the amount of product that can be made given the amount of limiting reactant available; dependent on l.r.*

2 breads + 1 cheese → 1 grilled cheese sandwich

$2B + C \rightarrow B_2C$

We can make: 11 sandwiches + 6 slices bread left over



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Predicting yields from limiting reactants

What mass of HCl can be produced when 3.0 moles of H_2 are reacted with 2.0 moles of Cl_2?

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

synthesis & redox reaction

24

Strategy: 1. Calculate yields of HCl from each reactant.
2. The lower yield is theoretical & indicates l.r.

$$\frac{3 \text{ mol } H_2}{} \cdot \frac{2 \text{ mol HCl}}{1 \text{ mol } H_2} \cdot \frac{36.46 \text{ g}}{1 \text{ mol HCl}} = 218.76 \rightarrow 220 \text{ g HCl}$$

$$\frac{2 \text{ mol } Cl_2}{} \cdot \frac{2 \text{ mol HCl}}{1 \text{ mol } Cl_2} \cdot \frac{36.46 \text{ g}}{1 \text{ mol HCl}} = 145.84 \rightarrow 150 \text{ g HCl}$$

limiting reactant

theoretical yield

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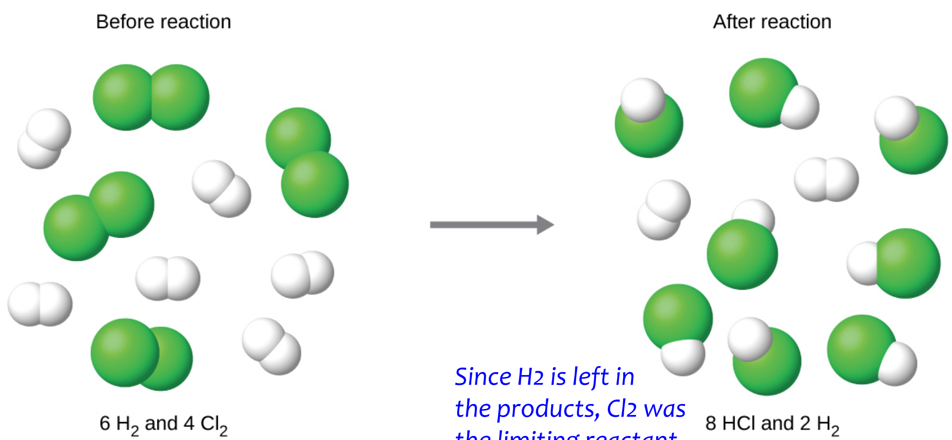
Predicting yields from limiting reactants

What mass of HCl can be produced when 6.0 moles of H_2 are reacted with 4.0 moles of Cl_2?

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$



Since H_2 is left in the products, Cl_2 was the limiting reactant.

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Try this

Silicon nitride is a hard, high-temperature-resistant ceramic used to make turbines for jet engines. It's made from Si and N_2: 25

$$3Si(s) + 2N_2(g) \rightarrow Si_3N_4(s)$$

How many grams of ceramic are made when 2.00 g of Si are reacted with 1.50 g of N_2?

limiting reactant **theoretical yield**

$$\frac{2.00\text{ g Si}}{}\;\frac{1\text{ mol Si}}{28.09\text{ g}}\;\frac{1\text{ mol }Si_3N_4}{3\text{ mol Si}}\;\frac{140.31\text{ g}}{1\text{ mol }Si_3N_4} = 3.33\text{ g }Si_3N_4$$

$$\frac{1.50\text{ g }N_2}{}\;\frac{1\text{ mol }N_2}{28.02\text{ g}}\;\frac{1\text{ mol }Si_3N_4}{2\text{ mol Si}}\;\frac{140.31\text{ g}}{1\text{ mol }Si_3N_4} = 3.76\text{ g }Si_3N_4$$

synthesis & redox reaction

58

One more

How many g of water are made when 5.00 g of H_2 reacts with 10.0 g of O_2:

26

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

synthesis & redox reaction

$$\frac{5.00\text{ g }H_2}{} \cdot \frac{1\text{ mol }H_2}{2.02\text{ g}} \cdot \frac{2\text{ mol }H_2O}{2\text{ mol }H_2} \cdot \frac{18.01\text{ g}}{1\text{ mol }H_2O} = 44.6\text{ g }H_2O$$

$$\frac{10.0\text{ g }O_2}{} \cdot \frac{1\text{ mol }O_2}{31.98\text{ g}} \cdot \frac{2\text{ mol }H_2O}{1\text{ mol }O_2} \cdot \frac{18.01\text{ g}}{1\text{ mol }H_2O} = 11.3\text{ g }H_2O$$

limiting reactant **theoretical yield**

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Percent yield

Percent yield: *a reaction's actual yield expressed as a percent of its theoretical yield*

- Percent yield is expected to be less than 100%.

$$\%\text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}}(100)$$

When 1.274 g of copper sulfate is reacted with excess Zn metal, 0.392 g of copper metal is produced. *What's the percent yield?*

$$Cu(SO_4)(aq) + Zn(s) \rightarrow Cu(s) + Zn(SO_4)(aq)$$

27

$$\frac{1.274\text{ g}}{} \cdot \frac{1\text{ mol }Cu(SO_4)}{159.57\text{ g}} \cdot \frac{1\text{ mol }Cu}{1\text{ mol }Cu(SO_4)} \cdot \frac{63.55\text{ g}}{1\text{ mol }Cu} = 0.5074\text{ g }Cu$$

$$\frac{0.392\text{ g}}{0.5074\text{ g}}(100) = 77.26\%\text{ yield}$$

60

Try this

What is the percent yield of a reaction that produces 12.5 g of Freon gas (CF_2Cl_2) from 32.9 g of CCl_4 and excess HF?

28

$$CCl_4 + 2HF \rightarrow CF_2Cl_2 + 2HCl$$

$$\frac{32.9\text{ g } CCl_4}{} \cdot \frac{1\text{ mol } CCl_4}{153.81\text{ g}} \cdot \frac{1\text{ mol } CF_2Cl_2}{1\text{ mol } CCl_4} \cdot \frac{120.91\text{ g}}{1\text{ mol } CF_2Cl_2} = 25.9\text{ g } CF_2Cl_2$$

$$\frac{12.5\text{ g}}{25.9\text{ g}}(100) = 48.26\%\text{ yield}$$

61

Can you?

(1) Define the terms limiting & excess reactants, theoretical yield and percent yield?

(2) Use stoichiometric conversion to determine which reactant is limiting?

(3) Use stoichiometric conversion to calculate theoretical yield?

(4) Calculate percent yield if actual yield is provided?

62

4. Stoichiometry of chemical reactions

4.5: Quantitative chemical analysis

- Describe the fundamental aspects of titrations & gravimetric analysis
- Perform stoichiometric calculations using typical titration & gravimetric data

63

Quantitative analysis

Quantitative analysis: *the determination of the amount or concentration of a substance in a sample using chemical reactions*

Example: 18th century – the strength (aka concentration) of vinegar was determined by measuring how much potassium carbonate had to be added before bubbling stopped.

$$2H(CH_3COO) + K_2(CO_3) \rightarrow \cancel{H_2(CO_3)} + 2K(CH_3COO)$$

$$2H(CH_3COO) + K_2(CO_3) \rightarrow CO_2 + H_2O + 2K(CH_3COO)$$

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Titration

Titration: *a technique that uses finely calibrated instruments (like **burets**) to measure the amounts of two reactants needed to react completely (the **equivalence point**).*

- *Stoichiometry (balanced chemical equation) must be known.*
- *The concentration (or amount) of one reactant must be known.*
- *End point indicator, showing reaction completion, must be used.*

Example: 18th century – the strength (aka concentration) of vinegar was determined by measuring how much potassium carbonate had to be added before bubbling stopped.

$$2H(CH_3COO) + K_2(CO_3) \rightarrow CO_2 + H_2O + 2K(CH_3COO)$$

stoichiometry

amount (g added)

endpoint fizzing stops

65

Titration calculations

Steps*:*

1. BCE → associate numerical info & goal.
2. Start with the known reactant and go to moles.
3. Stoichiometry to moles of the unknown.
4. Solve for volume or mass or concentration of the unknown.

The endpoint of titration of a 50.00-mL sample of aqueous HCl is reached after adding 35.23 mL of 0.250 M Na(OH) titrant. *What is the molarity of the HCl?* 29

$$HCl(aq) + Na(OH)(aq) \rightarrow NaCl(aq) + H_2O(l)$$

50.00 mL 35.23 mL
X M 0.250 M (mol/L)

mol
L

$$\frac{0.03523\ L \quad 0.250\ mol\ Na(OH) \quad 1\ mol\ HCl}{1\ L \quad 1\ mol\ Na(OH) \quad 0.050000\ L} = \frac{0.1762\ mol}{1\ L} = M$$

66

Try this

A 20.00-mL sample of aqueous oxalic acid, $H_2C_2O_4$, was titrated with a 0.09113 M solution of permanganate, $(MnO_4)^{-1}$. A volume of 23.24 mL was required to reach the end point.

30

What was the molarity of the oxalic acid?

$$5H_2C_2O_4 + 2(MnO_4)^{-1} + 6H^{+1} \rightarrow 10CO_2 + 2Mn^{+2} + 8H_2O$$

$$5H_2C_2O_4 + 2(MnO_4)^{-1} + 6H^{+1} \rightarrow 10CO_2 + 2Mn^{+2} + 8H_2O$$

20.00 mL   23.24 mL

X M   0.09113 M (mol/L)

mol / L

$$\frac{0.02324\ L \quad 0.09113\ mol\ (MnO_4)^{-1} \quad 5\ mol\ H_2C_2O_4}{1\ L \quad 2\ mol\ (MnO_4)^{-1} \quad 0.02000\ L} = \frac{0.2648\ mol}{1\ L} = M$$

67

Gravimetric analysis

Gravimetric analysis: *a sample is subjected to a change in physical state that allows separation of sample components.*

- Mass measurement or titration can then be used to quantitate components.

<u>Examples</u>:

(1) *the amount of water in a sample of forage is determined by measuring the mass of the sample before and after drying;*

(2) *an element is precipitated and filtered out of a mixture.*

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Gravimetric analysis via precipitation

A 0.4550-g solid mixture containing Mg(SO4) is dissolved in water and reacted with excess Ba(NO3)2, causing precipitation of 0.6168 g of Ba(SO4):

Mg(SO4)(aq) + Ba(NO3)2(aq) → Ba(SO4)(s)↓ + Mg(NO3)2(aq)

What was the percentage of Mg(SO4) in the original mixture? 31

Strategy: g Ba(SO4) → moles → moles Mg(SO4) → g → %

MW Ba(SO4) = 233.35 g/mol
MW Mg(SO4) = 120.33 g/mol

$$\frac{0.6168\text{ g}}{} \cdot \frac{1\text{ mol Ba(SO4)}}{233.35\text{ g}} \cdot \frac{1\text{ mol Mg(SO4)}}{1\text{ mol Ba(SO4)}} \cdot \frac{120.33\text{ g}}{1\text{ mol Mg(SO4)}} \cdot \frac{}{0.4550\text{ g}} \cdot 100 = 69.90\%$$

69

Try this

What is the percent of chloride ion in a sample of 1.1324 g of the sample produces 1.0881 g of AgCl when treated with excess silver ions?

32

$Ag^{+1}(aq) + Cl^{-1}(aq) \rightarrow AgCl(s)\downarrow$

Strategy: g AgCl → moles AgCl → moles Cl^{-1} → g → %

MW AgCl = 143.32 g/mol
MW Cl^{-1} = 35.45 g/mol

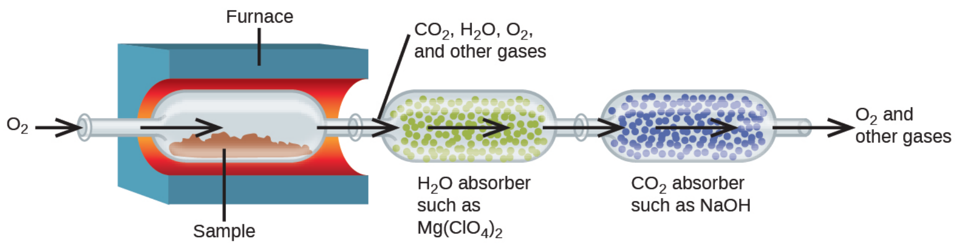
$$\frac{1.0881\text{ g}}{} \cdot \frac{1\text{ mol AgCl}}{143.32\text{ g}} \cdot \frac{1\text{ mol Cl}^{-1}}{1\text{ mol AgCl}} \cdot \frac{35.45\text{ g}}{1\text{ mol Cl}^{-1}} \cdot \frac{}{1.1324\text{ g}} \cdot 100 = 23.76\%$$

70

Gravimetric analysis via combustion

Combustion analysis: *a sample is combusted with excess oxygen, producing gaseous products that are separated and absorbed onto media, increasing the mass of that media.*

- Mass of each gas is calculated and used in analysis.
- Goal? Determination of empirical formula



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Combustion analysis of a hydrocarbon

Polyethylene is a hydrocarbon polymer used in food storage bags and flexible plastics. A combustion analysis of a 0.00126-g sample of polyethylene yields 0.00394 g of CO2 and 0.00161 g of H2O. *What is the empirical formula of polyethylene?*

$$C_xH_y(s) + O_2(g) \rightarrow xCO_2(g) + y/2H_2O(g)$$

Strategy: mass CO2 → mol CO2 → mol C ___ mol ratios
mass H2O → mol H2O → mol H

$$\frac{0.00394\text{ g}}{} \frac{1\text{ mol }CO_2}{43.99\text{ g}} \frac{1\text{ mol C}}{1\text{ mol }CO_2} = 8.96\text{ E-5 mol C}$$

$$\frac{0.00161\text{ g}}{} \frac{1\text{ mol }H_2O}{18.01\text{ g}} \frac{2\text{ mol H}}{1\text{ mol }H_2O} = 1.79\text{ E-4 mol H}$$

$$\frac{1.79\text{ E-4 mol H}}{8.96\text{ E-5 mol C}} = 1.9977 \rightarrow 2 \quad \text{so } CH_2$$

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Try this

Polystyrene is a hydrocarbon polymer used to make transparent but brittle products. A combustion analysis of a 0.00215-g sample of polyethylene yields 0.00726 g of CO2 and 0.00148 g of H2O. *What is the empirical formula of polystyrene?*

33

$$C_xH_y(s) + O_2(g) \rightarrow xCO_2(g) + y/2H_2O(g)$$

Strategy: mass CO_2 → mol CO_2 → mol C ___ mol ratios
mass H_2O → mol H_2O → mol H

$$\frac{0.00726\text{ g}}{} \; \frac{1\text{ mol }CO_2}{43.99\text{ g}} \; \frac{1\text{ mol C}}{1\text{ mol }CO_2} = 1.65\text{ E-4 mol C}$$

$$\frac{0.00148\text{ g}}{} \; \frac{1\text{ mol }H_2O}{18.01\text{ g}} \; \frac{2\text{ mol H}}{1\text{ mol }H_2O} = 1.64\text{ E-4 mol H}$$

$$\frac{1.64\text{ E-4 mol H}}{1.65\text{ E-4 mol C}} = 1 \quad \text{so CH}$$

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Can you?

(1) Use logic and all the beautiful manifestations of stoichiometric conversion to solve quantitative chemistry word problems?

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Module 4 Stoichiometry: terms to know

acid
acid-base reaction
actual yield
balanced chemical equation
base
buret
chemical equation
coefficient
combustion analysis
combustion reaction
complete ionic equation
end point
excess reactant
gravimetric analysis
half-reaction
insoluble
limiting reactant

molecular equation
net ionic equation
neutralization reaction
oxidation
oxidation number
oxidation-reduction reaction
oxidizing agent
percent yield
precipitate
precipitation reaction
product
quantitative analysis
reactant
reducing agent
reduction
salt
single-displacement reaction
solubility
soluble
spectator ion

stoichiometric factor
stoichiometry
strong acid
strong base
theoretical yield
titration analysis
weak acid
weak base

75