

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

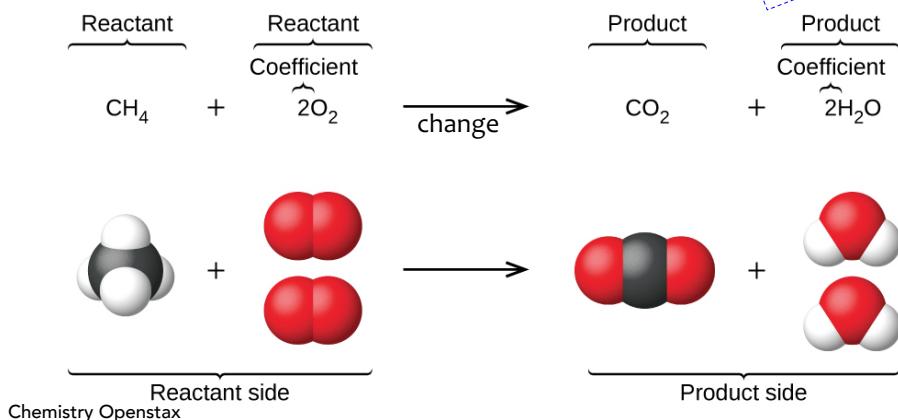
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Chemical equations



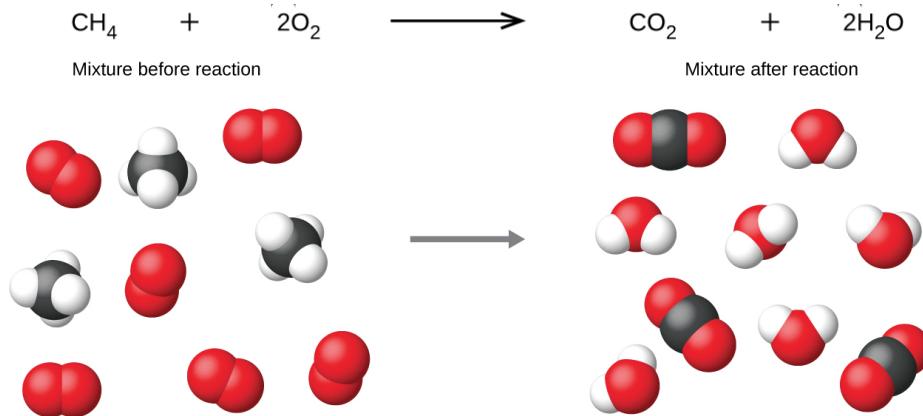
Reaction: one methane molecule reacts with two oxygen gas molecules to yield one carbon dioxide molecules and two water molecules.

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



3

Ratios are constant, amounts differ



Critical point:

Coefficients of balanced equations are counting units NOT mass.

atoms
molecules
moles

X

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4

Balancing equations



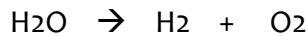
Chemical equations are **balanced** because the same number and type of atoms are found on both sides of the equation.

- 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:



decomposition
reaction

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Try these



Nitrogen and oxygen gas combine to form dinitrogen pentoxide.

- Use formulas to create a chemical equation.
- Add coefficients to balance the equation.

synthesis
(combination)
reaction

1

Ammonium nitrate decomposes to form nitrogen and oxygen gases and water.

- Use formulas to create a chemical equation.
- Add coefficients to balance the equation.

decomposition
reaction

2

6

3

Fractional coefficients (mainly for O₂)



Ethane (C₂H₆) is combusted.



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



Multiply through by 2 to remove the fraction.

combustion reaction

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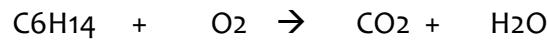
Try this



Hexane (C₆H₁₄) is combusted.

Write a balanced chemical equation.

3



combustion reaction

8

4

Noting physical state

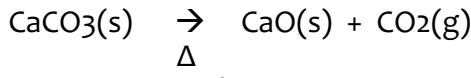


Chemical reactions often include notation of the physical states or reactants or products:

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



displacement
redox
reaction



decomposition
reaction

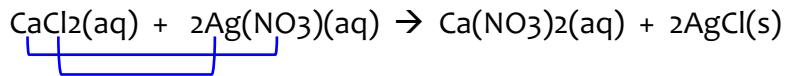
heat added

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Exchange reactions / dissociation



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

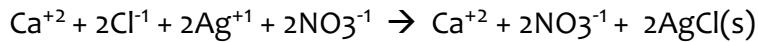


This is an **exchange reaction** in which two ionic compounds exchange ionic partners to create two new compounds.

- 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.



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Try this



Predict the products & balance this exchange reaction:



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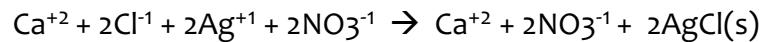
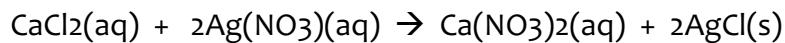
exchange reaction
(double displacement)

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Dissociation to ionic equations



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



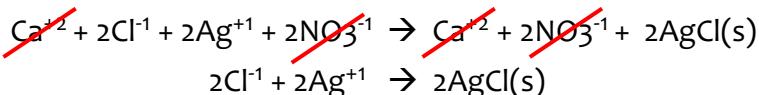
Notice that:

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

exchange reaction
(double dis)

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.



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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.

*exchange reaction
(double dis)*

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

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

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One more



Diatomeric 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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*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



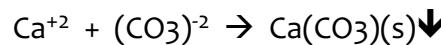
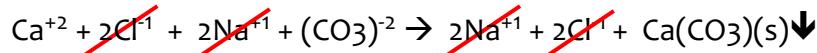
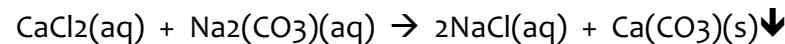
Precipitation reaction: two aqueous ionic solutions react via exchange to form two products; one product is a solid or **precipitate**

- 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).



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Predicting precipitation & solubility?



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(III)	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(III)	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

Thomson/Brooks Cole

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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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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 →

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Acid-base reactions



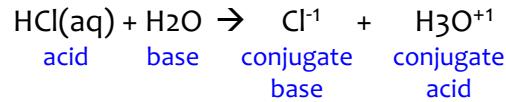
Acid-base reactions (aka neutralizations): hydrogen ion(s) (H^{+1}) are transferred from one *chemical* to another

- 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

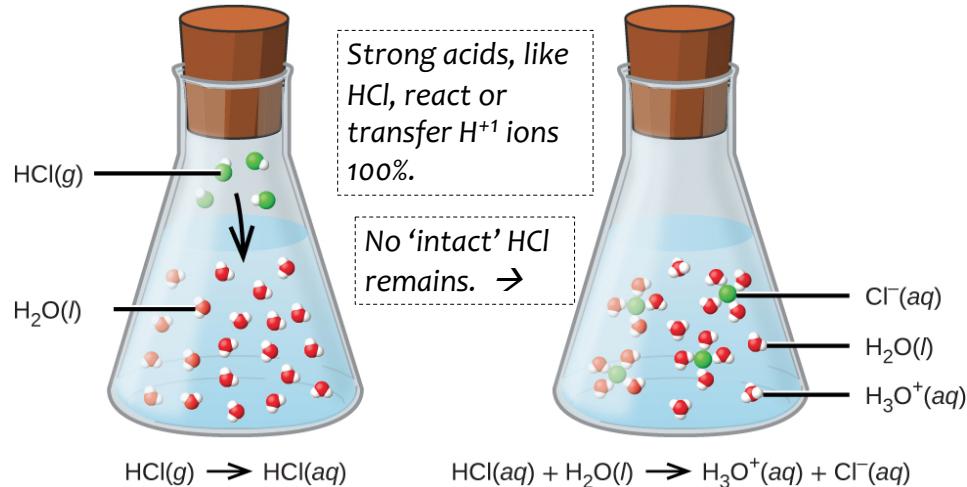
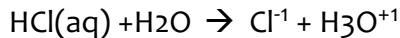
Acid: compound that dissociates in water & produces hydronium ion, H_3O^{+1}

- Acid formulas (usually) begin with 'H'



Strong acids \rightarrow 100% dissociation

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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

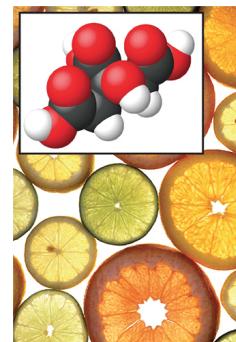
- Tangy fruit juice, sting of insect bites, vinegar, body odor



double arrow
indicates reversible,
weak acid, incomplete dissociation

- Only about 1% of acetic acid dissociates.
- This figure 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
HSO ₄	sulfuric acid
HClO ₃	chloric acid
HClO ₄	perchloric acid

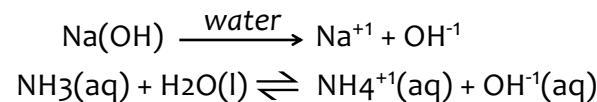
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Bases



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

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



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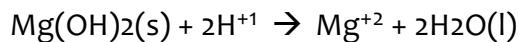
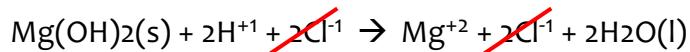
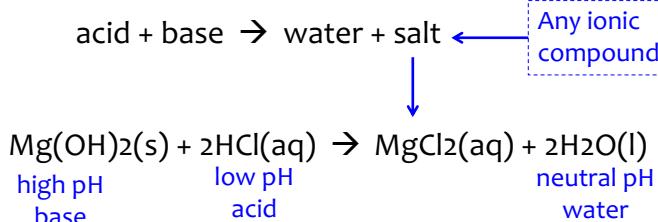
Neutralization reactions



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

- Neutralization reactions are exchange reactions.

Philips Milk
of Magnesia,
antacids



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Try these



The weak acid hydrogen hypochlorite reacts with water.

Write a balanced chemical equation.

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A solution of barium hydroxide is neutralized with nitric acid.

(a) *Write a balanced chemical equation.*

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(b) *Write complete & net ionic equations.*

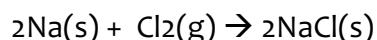
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Reduction-oxidation reactions



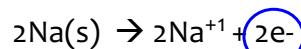
Earth's atmosphere is 21% oxygen gas (O_2) & this gas is vital for life on earth. Many reactions involve O_2 , and the term oxidation was originally used to describe these reactions.

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

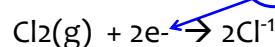


Notice both elements go from uncharged (elemental) to charged ions.

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



Each Na(s) loses one e^- .



Each atom in $\text{Cl}_2\text{(g)}$ 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**. an: a negative ion
- Oxidation numbers are reduced.
- Reduced elements are the **oxidizing agent**.

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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:

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- (a) H₂S
- (b) SO₃⁻²
- (c) Na₂(SO₄)

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

31

Try these



Assign oxidation numbers to all elements:

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- (a) K(NO₃)
- (b) AlH₃
- (c) NH₄⁺¹
- (d) H₂(PO₄)⁻¹

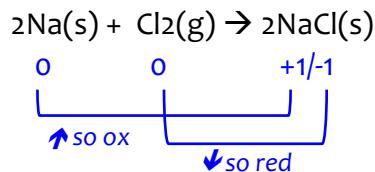
Note that S & N have to most variable oxidation numbers.

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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.



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Solid rocket fuel is combusted by this reaction.

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

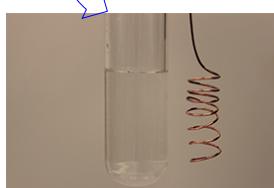
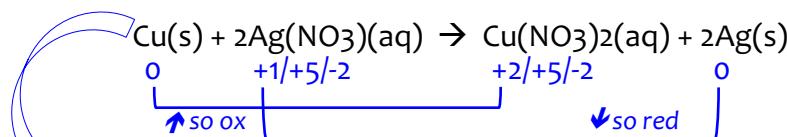
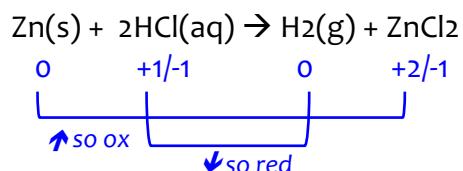


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Displacement reactions



Displacement reactions: metals are oxidized by acids or salts



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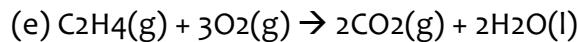
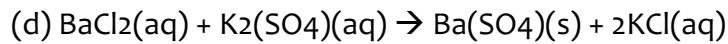
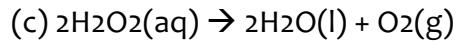
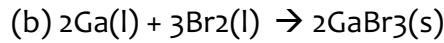
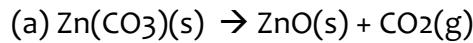
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Try this



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

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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.

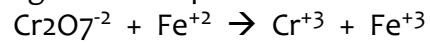
1. Separate the reaction into half-equations.
2. Balance all elements except O & H.
3. Balance O by adding one H_2O for every O needed.
4. Balance H by adding one H^{+1} for every H needed.
5. Balance charge by adding e^- to the more positive side.
6. If needed, multiply by factors to add the same number 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:



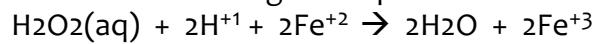
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Another



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



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

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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?

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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

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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.

~~12 s'mores~~ ~~2 graham crackers~~ = 24 graham crackers
~~1 s'more~~

~~12 s'mores~~ ~~2 chocolate bars~~ = 24 chocolate bars
~~1 s'more~~

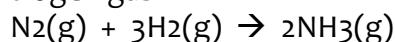
~~12 s'mores~~ ~~1 marshmallow~~ = 12 marshmallows
~~1 s'more~~

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The stoichiometry of chemical equations



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



synthesis
reaction

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

1 mole N₂

3 moles H₂

1 mole N₂

2 moles NH₃

3 mole H₂

2 moles NH₃

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

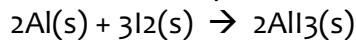
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So, try this



How many moles of I₂ are required to react with 0.429 mole of Al?



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synthesis reaction



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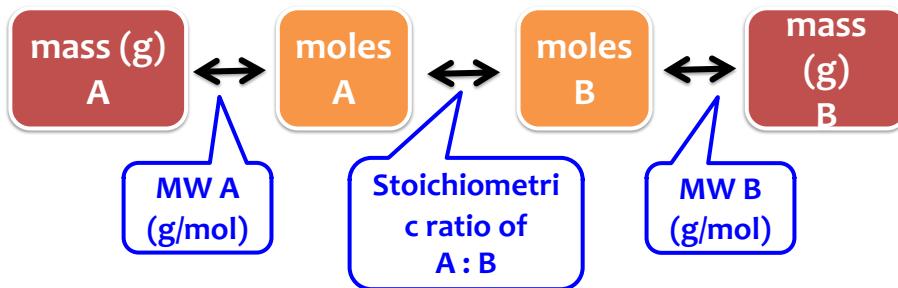
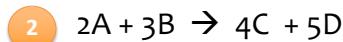
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Mole map for chemical reactions?



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.

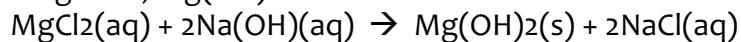


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Using this mass-mole map



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



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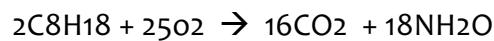
exchange
(double dis)
reaction

45

Try this



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



20

combustion
reaction

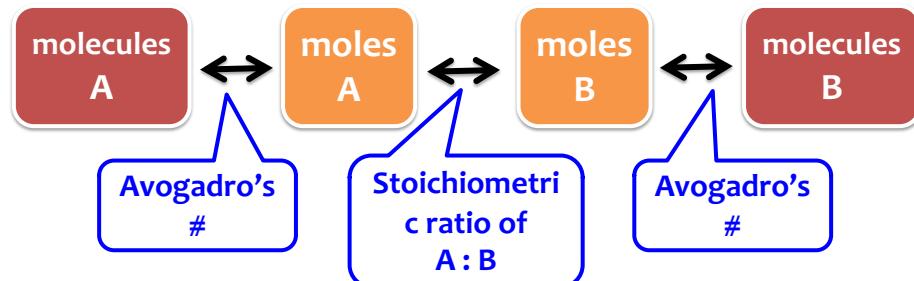
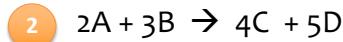
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Relating molecules to moles



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.



47

Using the molecule-mole map



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



21

combustion reaction

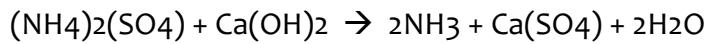
48

Try this



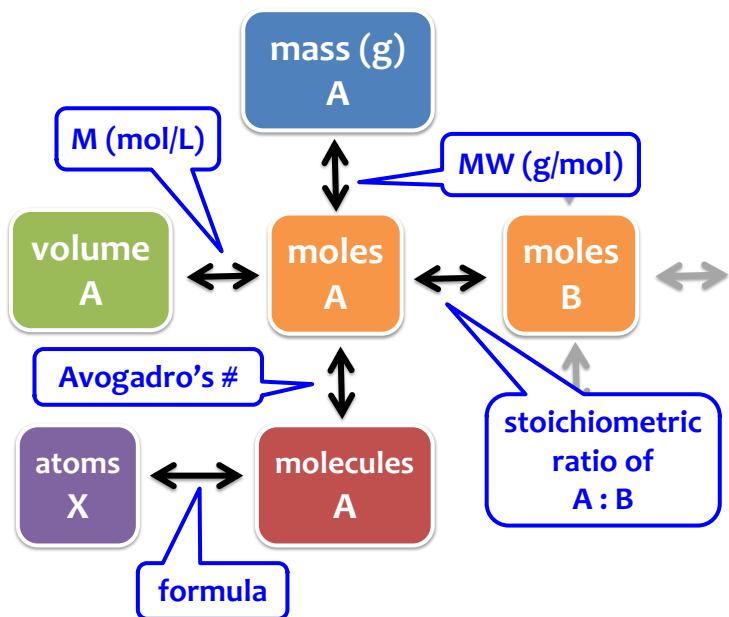
How many NH₃ molecules are produced by the reaction of 2.4 E24 molecules of Ca(OH)₂?

22



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Compiling a comprehensive mole map



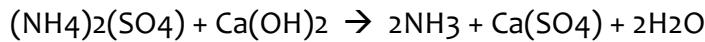
50

Test the comprehensive map



A mass of ammonium sulfate that contains 3.14×10^{25} 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



51

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

53

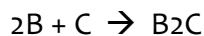
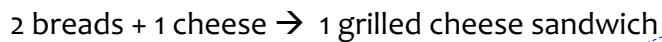
Limiting reactants



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.

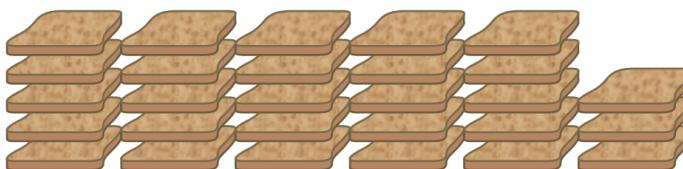


synthesis
reaction

Provided with:

28 slices of bread

+ 11 slices of cheese



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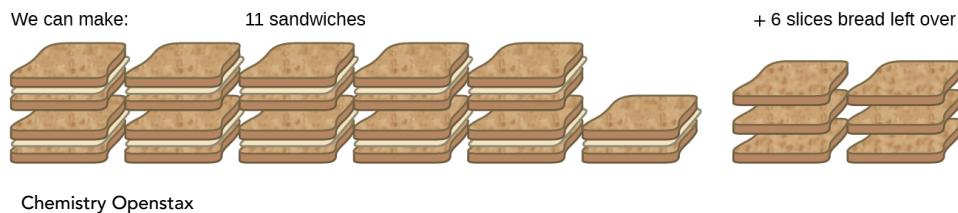
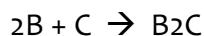
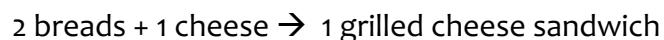
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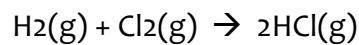


55

Predicting yields from limiting reactants



What mass of HCl can be produced when 3.0 moles of H₂ are reacted with 2.0 moles of Cl₂?



synthesis &
redox
reaction

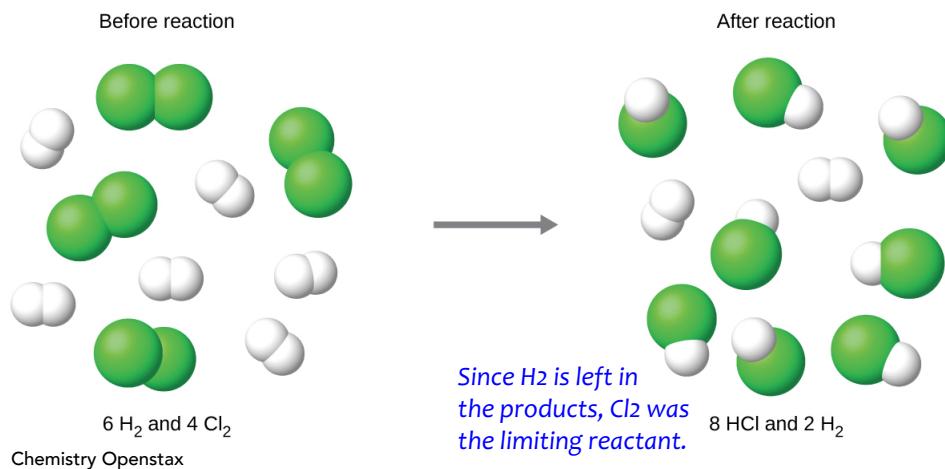
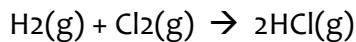
24

56

Predicting yields from limiting reactants



What mass of HCl can be produced when 6.0 moles of H₂ are reacted with 4.0 moles of Cl₂?

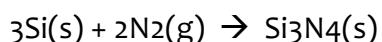


57

Try this



Silicon nitride is a hard, high-temperature-resistant ceramic used to make turbines for jet engines. It's made from Si and N₂:



25

How many grams of ceramic are made when 2.00 g of Si are reacted with 1.50 g of N₂?

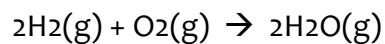
synthesis & redox reaction

58

One more



How many g of water are made when 5.00 g of H₂ reacts with 10.0 g of O₂:



26

synthesis & redox reaction

59

Percent yield

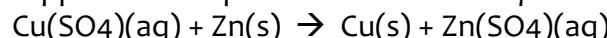


Percent yield: a reaction's actual yield expressed as a percent of its theoretical yield

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

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

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?



27

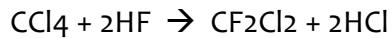
60

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



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

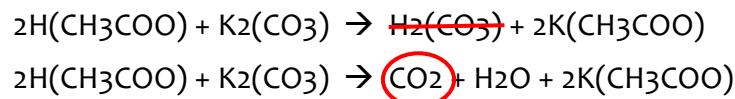
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Quantitative analysis



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.



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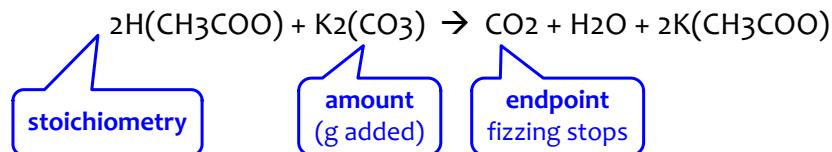
Titration



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.



65

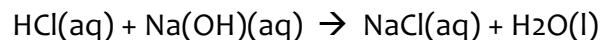
Titration calculations



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. 29



66

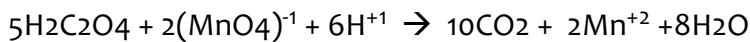
Try this



A 20.00-mL sample of aqueous oxalic acid, $\text{H}_2\text{C}_2\text{O}_4$, was titrated with a 0.09113 M solution of permanganate, $(\text{MnO}_4)^{-1}$. A volume of 23.24 mL was required to reach the end point.

What was the molarity of the oxalic acid?

30



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.

Examples:

(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):



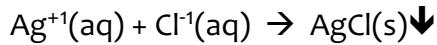
What was the percentage of Mg(SO₄) in the original mixture? 31

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


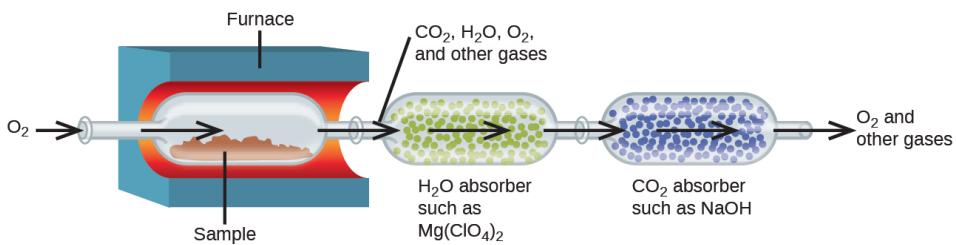
70

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?



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

$$\frac{0.00394 \text{ g}}{43.99 \text{ g}} \frac{1 \text{ mol CO}_2}{1 \text{ mol CO}_2} \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 8.96 \text{ E-5 mol C}$$

$$\frac{0.00161 \text{ g}}{18.01 \text{ g}} \frac{1 \text{ mol H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 1.79 \text{ E-4 mol H}$$

$$\frac{1.79 \text{ E-4 mol H}}{8.96 \text{ E-5 mol C}} = 1.9977 \rightarrow 2 \quad \text{so CH}_2$$

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72

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

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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	molecular equation	stoichiometric factor
acid-base reaction	net ionic equation	stoichiometry
actual yield	neutralization reaction	strong acid
balanced chemical equation	oxidation	strong base
base	oxidation number	theoretical yield
buret	oxidation-reduction reaction	titration analysis
chemical equation	oxidizing agent	weak acid
coefficient	percent yield	weak base
combustion analysis	precipitate	
combustion reaction	precipitation reaction	
complete ionic equation	product	
end point	quantitative analysis	
excess reactant	reactant	
gravimetric analysis	reducing agent	
half-reaction	reduction	
insoluble	salt	
limiting reactant	single-displacement reaction	
	solubility	
	soluble	
	spectator ion	