

Cpt 3. CHEMICAL EQUATIONS & REACTIONS

Objective: Describe, explain, predict and write balanced equations for chemical reactions

3.1. Chemical Reaction

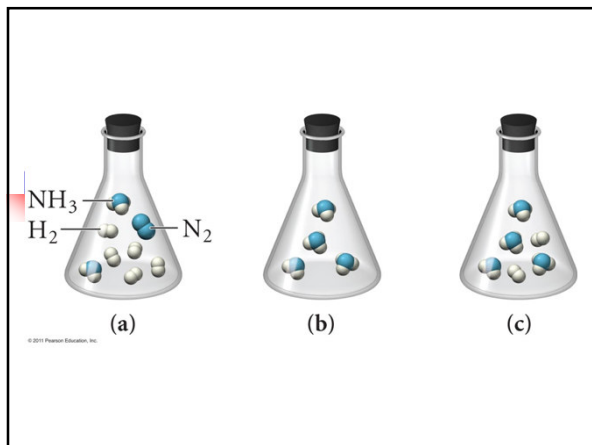
- **Thought teaser: DEMO from CD1:** combustion of propane
- Fate of **old bonds**?
- Fate of **Initial substances**?
- **Number of atoms** in starting substances and new substances?

RQ2-14

- Considering the correct answer to the last question, what physical property of substances is maintained through a chemical reaction?
 - a. The **volume**. **Equality in number of atoms** of starting and ending substances **means equality in their volumes**.
 - b. The **mass**. **Equality in number of atoms** of starting and ending substances **means equality in their masses**.
 - c. The **density**. **Equality in number of atoms** of starting and ending substances **means equality in their densities**.

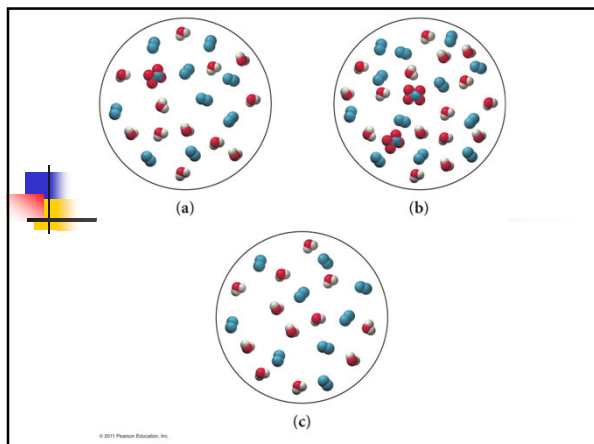
Chemical Reaction: Overview

- **Definition:** a process in which substances are changed into other (new) substances
- **Components**
Reactants: Starting materials for a reaction
Products: chemicals produced by a reaction
Ex: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- **Observation: All atoms found in the reactants** are also found **in the products**
- **Law of conservation of matter:** "matter can be neither created nor destroyed" (A. LAVOISIER).
- **Caution:** the law is valid in the **classical** meaning of a chemical reaction.



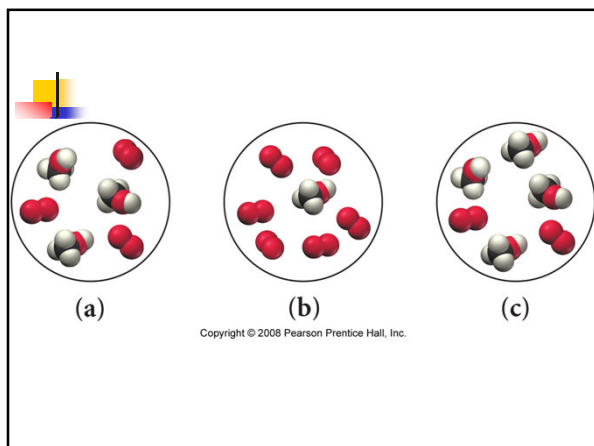
RQ2-14b1

- Which flask shows when the reaction has reached completion?
 - A, Because it has more substances
 - B, because it has no reactants left
 - C, because it shows reactants and products



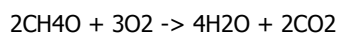
RQ2-14b2

- The previous graphic shows the following reaction: $2 \text{N}_2\text{H}_4 + \text{N}_2\text{O}_4 \rightarrow 3 \text{N}_2 + 4 \text{H}_2\text{O}$. Which picture shows when the reaction has reached completion?
 - a. A, because it shows all molecules involved in the reaction
 - b. B, because it has the highest amount of substances
 - c. C, because it shows products only



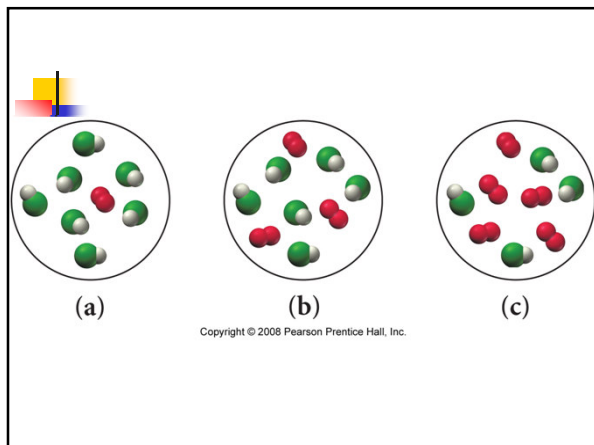
RQ2-14b3

- The pictures in the previous slides show reaction mixtures for this reaction:



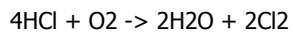
Which mixture will produce the highest amount of CO_2 ? Justify your answer.

- Mixture a.** It produces **6 CO_2** molecules
- Mixture b.** It has **6 O_2** molecules
- Mixture c.** It produces **4 CO_2** molecules



RQ2-14c

- The pictures in the previous slides show reaction mixtures for this reaction:



Which mixture will produce the highest amount of Cl_2 ? Justify your answer.

- Mixture a.** It has the **7 HCl** molecules
- Mixture b.** It produces **3 Cl_2** molecules
- Mixture c.** It has **5 O_2** molecules



Chemical Equation

- **Case Study:** $2\text{Fe} + 3\text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 3\text{H}_2$
- **Definition: Mathematical** equation used to show the **relation** between the **reactants** and the **products** of a chemical reaction
- **Rule:** all chemical equations must be **balanced**.
The **#'s of atoms on the left = #'s of atoms on the right**
- **Stoichiometric Coefficients:** Numbers **preceding formulas** in an equation, used to:
 - * show the **# of atoms/molecules** of reactants and products used in a reaction
 - * balance the chemical equation



3.2. Driving forces of Chemical Reactions

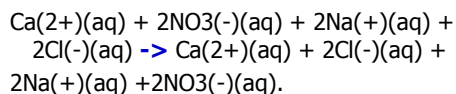
What makes a reaction occur (Driving Force)?

- * **Case Study 1:** $\text{AgNO}_3(\text{aq}) + \text{NaCl}(\text{aq}) \rightarrow \text{AgCl}(\text{s}) + \text{NaNO}_3(\text{aq})$.
- Aq = aqueous (water) solution.
- s = Solid
- $\text{Ag}^+(\text{aq}) + \text{NO}_3^-(\text{aq}) + \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s}) + \text{Na}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$.
- Reaction **works. Why?** (Hint: cancel identical terms on both sides)



Driving forces of Chemical Reactions

- **Case Study 2:** $\text{Ca}(\text{NO}_3)_2(\text{aq}) + 2\text{NaCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + 2\text{NaNO}_3(\text{aq})$



- Reaction **does not work. Why?** (Hint: cancel identical terms on both sides)



Driving Forces (Continued)

- **a. Formation of an Insoluble Compound (precipitate).**

A.k.a. **Precipitation** reaction. **Product = insoluble** in reaction solvent.

Driving force: product imbalance caused by withdrawal of the insoluble product from the ion count in the solution

Solubility rules: pg 149, table 4.1



Driving Forces (Continued 2)

- **b. Formation of a gas**

ex: $\text{H}_2\text{SO}_4(\text{l}) + \text{NaCl}(\text{aq}) \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + \text{HCl}(\text{g})$

The gas escapes from reaction medium.

Driving force: product imbalance caused by withdrawal of the gas product from the ion count in the solution



Driving Forces (Continued 3)

- **c. Formation of a weak or non electrolyte**

Ex: $\text{NaOH}(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$

Unlike reactants, product does not dissociate in solution.

Driving force: product imbalance caused by withdrawal of the weak electrolyte from the ion count in the solution

Reactions Driving Forces (Examples)

- # # 72c , d, pg 174
 - **Complete** the reaction
 - **Does it work or not?** (Hint: check pg 154)
- c. $(\text{NH}_4)_2\text{SO}_4(\text{aq}) + \text{SrCl}_2(\text{aq}) \rightarrow ?$
- d. $\text{NH}_4\text{Cl}(\text{aq}) + \text{AgNO}_3(\text{aq}) \rightarrow ?$
- **Extra ex:** # 71c, 81, pg 174

RQ2-15

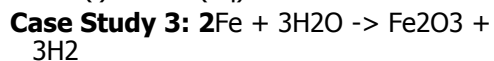
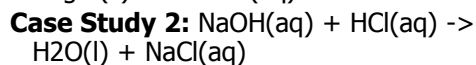
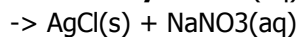
- **Does the reaction** $\text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ **work?** Justify your answer.
- a. **Yes.** The formation of the **gas that escapes** is a **stronger driving force** than the **solid that stays** in the reaction mixture.
- b. **No.** The formation of the **gas that escapes** is a **weaker driving force** than the **solid that stays** in the reaction mixture.
- c. **Yes.** The formation of the **gas that stays** is a **stronger driving force** than the **solid that escapes** in the reaction mixture.

RQ2-15B: Previous Material Review

- In the **equation of a chemical reaction**, there is **equality between the numbers** of: a, **atoms**; b, **molecules**; c, **ions** on the left and on the right of the equation arrow.
- In order for a reaction to work, it needs: a, **temperature**; b, a **driving force**; c, a **catalyst**
- The **driving force** of the reaction $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$ is: a, **none**; b, the formation of **CaO solid**; c, the formation of **CO₂ gas**.

3.3. Types of Chemical Reactions

Classification criterion: **type of particle exchanged** in the reaction



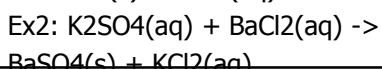
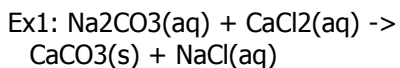
3.3. Types of Chemical Reactions

a. Ion Exchange Reactions

Reactions between ionic compounds

Reactants exchange ions

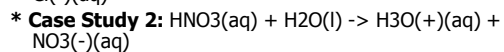
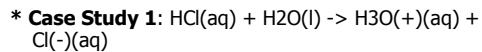
Reactions happen without change in Oxidation Numbers



b. Acid-Base Reactions.

Thought teasers:

* **DEMO:** CD 1



Common reaction characteristic of HCl and HNO₃?



What type of substance does CO₂ generate in water?



*1. Acid

■ **Definition:** molecule or ion that **releases protons** (H(+))

■ **Acidic compounds:** made of **H(+)** and:

***nonmetal anions** from columns (VI, and VII)A.

Examples: HCl, H₂S, HF, ...

* **Polyatomic Anions** (see list on pg 91)

Examples: HNO₃, H₃PO₄, ...

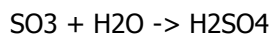
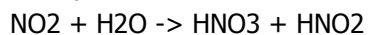


Acids (continued)

■ **Acidic oxides**

= oxides of non-metals. They **generate acids** after reaction with water.

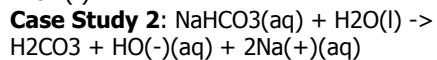
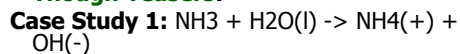
Examples: NO₂, SO₃, ...



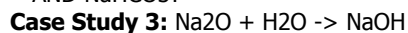


*2. Base

■ **Thought Teasers:**



Common reaction characteristic of NH₃ AND NaHCO₃?



What type of substance does Na₂O generate in water?



Bases

- **Definition:** molecule or ion that attracts $H(+)$
 - **Basic compounds:**
Compounds of:
 - * **N bound to C**, and/or H using single bonds
- Examples:** H_3C-NH_2 , $(CH_3)_2NH$, $(CH_3)_3N$, ...
- * **OH(-) or CO₃(2-)** and metal cations
- Examples:** $NaOH$, $Ca(OH)_2$, Na_2CO_3 , ...



Bases (Continued)

- **Basic oxides**
= oxides of metals. They form hydroxide bases after reaction with water.
- Examples: CaO , Li_2O , ...
- $CaO + H_2O \rightarrow Ca(OH)_2$
- $Li_2O + H_2O \rightarrow 2LiOH$



*3. Neutralization

- **Definition:** Acid-base reaction: a proton is transferred from a Bronsted acid to a Bronsted base.
- ex: $3NH_3 + H_3PO_4 \rightarrow (NH_4)_3PO_4$
- ex2: $Na_2CO_3 + 2HCl \rightarrow H_2CO_3 + 2NaCl \rightarrow H_2O + CO_2 + 2NaCl$

Ion Exchange & Acid-Base Reactions (Illustrations)

Examples:

* #71d, pg 179

■ **Extra exercise:** rest of #71

* # 78 b, pg 179

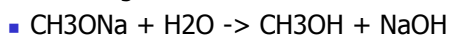
Extra exercise : #77, pg 179

* #82 a, pg 180

Extra exercise : #81, pg 180

RQ2-15b

■ Indicate the acid and the base in the following reaction:



a. **Acid: H₂O.** It attracts a H(+); **base: CH₃ONa:** It releases a proton

b. **Base: CH₃ONa.** It attracts a H(+); **Acid: H₂O:** It releases a proton

c. **Acid: CH₃ONa.** It releases a H(+); **base: H₂O:** It attracts a proton

RQ2-16

■ How do you explain that mixing water solutions of N₂O₄ and Na₂O leads to the production of NaNO₃?

a. **Water solutions of N₂O₄ and Na₂O** produce **HNO₃ and NaOH** respectively, and the products **react to produce NaNO₃**

b. **Water solutions of N₂O₄ and Na₂O** produce **NaOH and HNO₃** respectively, and the products **react to produce NaNO₃**

c. **NaNO₃** must have been **added** to the water **before making the solutions**

RQ2-16B, Previous Material Review

- Definitions of Acids and Bases
 - a. Acids release protons and bases attract protons
 - b. Acids attract protons and bases release protons
 - c. Acids release cations and bases attract cations
- In order for a reaction to work it needs: a, cations; b, anions; c, driving force

RQ2-16B, Previous Material Review 2

- In the following list: C_2H_7N (no multiple bonds in the molecule), K_2HPO_4 , H_3PO_3 , $Mg(OH)_2$, $Al_2(CO_3)_3$, H_2CO_3 , $Ca(HCO_3)_2$
- the acids are, from left to right:
 - a. H_3PO_3 and H_2CO_3 .
 - b. $Mg(OH)_2$ and $Al_2(CO_3)_3$

RQ2-16B, Previous Material Review 3

- According to the description of acidic and basic oxides, in the following list, BeO , P_2O_5 , SeO_3 , K_2O , SiO_2 , and SrO , acidic oxides are, from left to right:
 - a. BeO , K_2O , and SrO
 - b. P_2O_5 , SeO_3 , and SiO_2

c. Oxidation-Reduction (Redox) Reactions

- Particle exchanged between reactants: electron
- Demo:**
- Case Study:** $2\text{Fe} + 3\text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 3\text{H}_2$
ON:
Lost electrons:
Loss-causing agent:
Gained electrons:
Gain-causing agent:

Oxidation & Reduction (Continued)

- Oxidation:** a process in which an atom loses electrons (its ON increases)
ex: $\text{Na} - 1e \rightarrow \text{Na}^+$
- Oxidizing agent:** substance that causes oxidation
oxidizing agent contains the atom that takes electrons

Reduction

- Definition:** process in which an atom or ion gains electrons (its ON decreases)
- ex: $\text{Cl}_2 + 2e \rightarrow 2\text{Cl}^-$
- Reducing agent:** Substance that causes reduction. Contains atom that gives electrons
- Oxidation and reduction** always occur **simultaneously**
One atom gives electrons and another one takes them.

Identification of a redox reaction

- Check for **change in oxidation numbers** of atoms in the reaction.
- find the **oxidation and reduction half reactions**.
- ex: $\text{Zn} + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2$

ON:

Oxidized:

Oxidizing agent:

Reduced:

Reducing agent:

Extra ex: #88a, d, #87, pg 175

RQ2-17

- Examine the following reaction:



ON +1/+5/-2 +1/+7/-2 +1/-1

What atom is **oxidized**, what atom is **reduced**? Which substance is the **oxidizing**, which one is the **reducing agent**?

Note: a **compound** is made of **more than one molecule**.

RQ2-17 (Continued)

Answers:

- Oxidized** atom: **Cl(+7)**. **Loses electrons** to form Cl(+5). **Reduced:** Cl(-1), **gains electrons** to form Cl(+5).
- Oxidized** atom: **Cl(+5)**. **Loses electrons** to form Cl(+7). **Reduced:** Cl(+5), **gains electrons** to form Cl(-1).
- Oxidized** atom: **O(-6)**. **Loses electrons** to form O(-8). **Reduced:** Cl(+5), **gains electrons** to form Cl(-1).

3.4. Balancing Chemical Equations

- Check for change in ON.
- No change → nonredox reaction
- Change → redox reaction
- a. Balancing a nonredox equation**
- 1. Balance substances associated with the most complex molecule 1st
- 2. Balance the other molecules as directed by the previous balancing
- Ex: $\text{Ca(OH)}_2 + \text{H}_3\text{PO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + \text{H}_2\text{O}$

Illustration

- $\text{Ca(OH)}_2 + \text{H}_3\text{PO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + \text{H}_2\text{O}$
- Most complex molecule: $\text{Ca}_3(\text{PO}_4)_2$.
- $3\text{Ca(OH)}_2 + 2\text{H}_3\text{PO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + \text{H}_2\text{O}$
- Balance the rest of the equation
- $3\text{Ca(OH)}_2 + 2\text{H}_3\text{PO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + 6\text{H}_2\text{O}$

RQ2-18

- Examine the following reactions:
Equation 1: $\text{Al(NO}_3)_3 + \text{Na}_2\text{CO}_3 \rightarrow \text{Al}_2(\text{CO}_3)_3 + \text{NaNO}_3$
Equation 2: $\text{Al}_2(\text{NO}_3)_3 + \text{Na}_2\text{CO}_3 \rightarrow \text{Al}_2(\text{CO}_3)_3 + \text{Na}_2(\text{NO}_3)_3$
Is equation 2 the balanced form of equation 1? Justify your answer.

RQ2-18 (Answer)

- Answers to RQ2-18
- a. **YES**, because the **substances on the left of the arrow** are the **same as on the right**.
- b. **Yes**, because the **number of atoms on the left of the arrow** is the **same as on the right**.
- c. **No**, because the **substances with changed subscripts** are **no longer the same** as in the original equation.

RQ2-17B: Previous Material Review

- If the oxidation number of an atom increases, the atom: a, **gains electrons and is oxidized**; b, **loses electrons and is oxidized**; c, **loses electrons and is reduced**
- When balancing a chemical equation, the numbers used to do the balancing are added as: a, **superscripts at the left**, b, **subscripts at the right**, c, **coefficients at the left** of reactants and products.

RQ2-17B2: Previous Material Review

- Examination of the following reaction:
$$\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$$

ON +2/-2 2(+1)/-2 +4/2(-2) 0
- Leads to the conclusion that **H** is being: a, **oxidized**; b, **reduced**; c, **neutralized**.
- In the reaction, **H₂O** is the: a, **reducing**; b, **oxidizing**; c, **cooling** agent
- When **balancing a redox reaction**, the **goal** is to achieve **equality between**: a, **stoichiometric** coefficients; b, **oxidation and reduction** coefficient; c, **total increase and total decrease** in oxidation numbers

WORD OF WISDOM

Learning Steps

- **Resolve, Dare** to make the **first step** in the **learning process**:
REVIEW
- Reviewing leads to **UNDERSTANDING**
- **Don't understand?** **Ask quickly for help** to **keep the momentum**

WORD OF WISDOM

- Not enough **time**?
- **MAKE** the time!
- **Sacrifice** something.
- Your **better future**: worth the sacrifice

b. Balancing a redox equation

- Method used: **change in oxidation number**
- **Principle**: For a balanced equation, **total increase in ON = total decrease in ON = LEAST COMMON MULTIPLE** of **ON increase & ON decrease**

Balancing a redox equation: Procedure

- **Step 1:** Assign oxidation #'s to all atoms.
- **Step 2:**
 - * Determine **ON changes**.
 - * Find the **LCM** of on increase and decrease.
 - * Find the **coefficients** needed to get the LCM:
 - **Oxidation coefficient:** multiplies the **ON increase** to get LCM
 - **Reduction coefficient:** multiplies the **ON decrease** to get LCM

Balancing a redox equation: Procedure (Continued)

- **Step 3:** balance **oxidized and reduced species** (they are directly involved in redox process):
 - * **multiply oxidized** species by the **oxidation coefficient**
 - * **multiply reduced** species by the **reduction coefficient**
- **Step 4:** **Balance rest of the equation** as directed by previous balancing
- **Example:** $\text{Cu} + \text{HNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + \text{NO} + \text{H}_2\text{O}$

Balancing a redox equation (Illustration)

- $\text{HNO}_3 + \text{C}_2\text{H}_6\text{O} + \text{K}_2\text{Cr}_2\text{O}_7 \rightarrow \text{KNO}_3 + \text{C}_2\text{H}_4\text{O} + \text{Cr}(\text{NO}_3)_3 + \text{H}_2\text{O}$
- ON's:
- Oxidized:
- Reduced:
- LCM:
- Balancing: **RQ2-19**
- **Extra ex:** $\text{KClO}_3 + \text{HBr} \rightarrow \text{Br}_2 + \text{H}_2\text{O} + \text{KCl}$

RQ2-19

- What should you do after finding the LCM of increase and decrease in ON?
- a. Multiply the **C side by 1** and the **N side by 3**
- b. Multiply the **C side by 3** and the **Cr side by 1**
- c. Multiply the **C side by 1** and the **Cr side by 3**

Balancing redox equations (Illustrations, continued)

- Extra exercises: balance the following equations
- $K_2SO_3 + KMnO_4 + HCl \rightarrow K_2SO_4 + MnCl_2 + H_2O + KCl$
- $K_2S_2O_3 + Cl_2 + H_2O + KNO_3 \rightarrow K_2SO_4 + KCl + HNO_3$
- $KBiO_3 + HCl + MnCl_2 \rightarrow BiCl_3 + H_2O + KMnO_4 + KCl$

RQ2-19B: Previous Material Review

- In balancing a complex redox equation, the first step is to: a, **balance the oxidized and reduced species**; b, **find the oxidation number of all atoms**; c, **find the ON of all reduced and oxidized atoms only**.
- After the LCM-related oxidation and reduction coefficients are found, the **side of the reaction that is reduced** is multiplied by the: a, **oxidation**; b, **reduction**; c, **LCM** coefficient in order for that side to get balanced
