COURSE - MINT CHEMISTRY

TOPIC 5
Chemical Reactions

MONTANUNIVERSITÄT LEOBEN Chair of General and Analytical Chemistry © Thomas Prohaska 2022

Chemical Reactions

Chemical reactions are processes in which one (or more) substance(s) are transformed

Condition 1 Condition 2

$$C + O_2 \leftrightharpoons CO_2$$

The state of a system is described by the
state variables

pressure (p), volume (V), amount of substance (n) temperature (T)

Chemical Reactions

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Condition 1		Condition 2
$C + O_2$	$\leftrightharpoons$	CO_2
Source materials	$\leftrightharpoons$	End materials
Educts	$\leftrightharpoons$	Products
Reactants	$\leftrightharpoons$	Products
Left side	$\leftrightharpoons$	Right side

In chemical reactions, atoms are "rearranged" but not lost or added!

CLASSIFICATION OF CHEMICAL REACTIONS

- Exchange and rearrangement reactions
  (mostly work according to the acceptor/donator principle)
  - Acid/base reactions
  - Redox reactions (Reduction/Oxidation)
  - Dissolution/precipitation reactions
  - Complexometric/-dissociation reactions

Reaction Equations

indicate:

which reaction partners (= reactants, reagents) react with each other and which substances are formed in this reaction

how many molecules, atoms or ions react with each other

(= Reaction stoichiometry)

$$C + O_2 \leftrightharpoons CO_2$$

$$2H_2 + O_2 \leftrightharpoons 2H_2O$$

Reaction equations indicate how many particles react with each other

$$1\ H_2 + {}^{1}/_{2}O_2 \rightleftharpoons 1\ H_2O$$

Reaction equations indicate how many moles react with each other

$1\ H_2 + {}^1/_2 O_2 \rightleftharpoons 1\ H_2O$

$1\ \text{mol}\ H_2 + 0.5\ \text{mol}\ O_2 \rightleftharpoons 1\ \text{mol}\ H_20$

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Reaction equations indicate how many grams react with each other

$1\ H_2 + {}^1/_2 O_2 \rightleftharpoons 1\ H_2O$

$1\ \text{mol}\ H_2 + 0.5\ \text{mol}\ O_2 \rightleftharpoons 1\ \text{mol}\ H_20$

$2.016\ \text{g}\ H_2 + 15.999\ \text{g}\ O_2 \rightleftharpoons 18.015\ \text{g}\ H_2O$

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Stoichiometric Coefficients

have the task of ensuring that exactly the **same number of each atom is on the left and on the right**:

$$2 * H_2 + 1 * O_2 \rightleftharpoons 2 * H_2O$$

stoichiometric coefficients

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Physical state of the substances involved

In addition, you can also write the physical state of the individual substances in brackets:

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$

(s)	...solid
(l)	...liquid
(g)	...gaseous
(aq)	...aqueous

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Condition 1 Condition 2

$$\mathrm{C} + \mathrm{O_2} \leftrightharpoons \mathrm{CO_2} \qquad \Delta H < 0$$

ΔH – Reaction enthalpy

$\Delta H < 0$ – heat is released
exothermic

$\Delta H > 0$ – heat is absorbed
endothermic

Energy (e.g. in the form of heat ΔH) is released or consumed.

Chemical Equations

A chemical equation is balanced

1) when there is the same number of atoms of an element on both sides
(**ATOM BALANCE**)

2) if there is the same total charge on both sides
(**CHARGE BALANCE**)

Balancing a combustion reaction

Methane combusts with oxygen to form carbon dioxide and water

$CH_4 + O_2 \rightleftharpoons CO_2 + H_2O$

Tutorial:

Start balancing with the atom that occurs least frequently (in this case, C and H):

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

Then O:

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

Finally, the states of matter:

$CH_4(g) + 2\ O_2(g) \rightleftharpoons CO_2(g) + 2\ H_2O(g)$

Balancing reaction equations

Iron(III) oxide reacts with carbon to form iron and carbon dioxide.

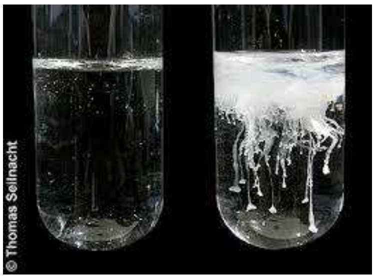
Set up the reaction equation:

$Fe_2O_3\ (s) + 3C\ (s) \rightleftharpoons 3\ CO_2(g) + 2Fe\ (s)$

Net ionic- and Overall-Reactions

Net ionic reactions ONLY consider the reactants.

Example: You dissolve sodium chloride in water. You add a solution of silver nitrate to this solution. Silver chloride precipitates out. Write down the **net ionic reaction** of this precipitation reaction.



Silver chloride = AgCl

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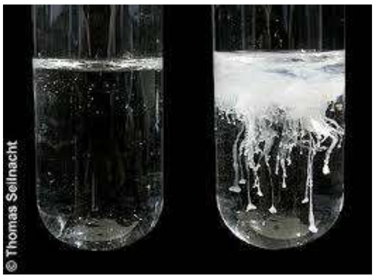
$AgNO_3$ - Solution:

NaCl Solution:



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in H_2O

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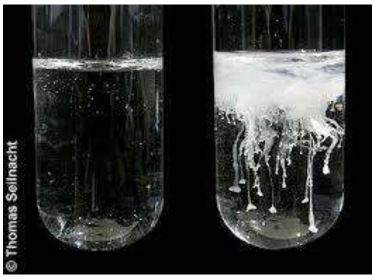

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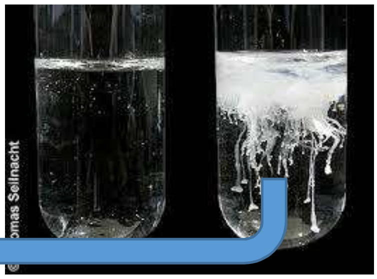

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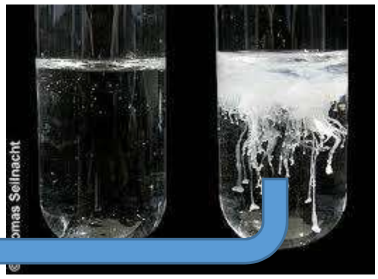

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$$Ag^+ + Cl^- \rightleftharpoons AgCl$$

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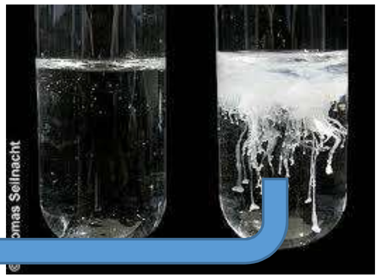

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$$Ag^+ + Cl^- \rightleftharpoons AgCl$$

$$Na^+ + Ag^+ + NO_3^- + Cl^- \cancel{\rightarrow} AgCl + Na^+ + NO_3^-$$

Overall reaction – NOT NEEDED

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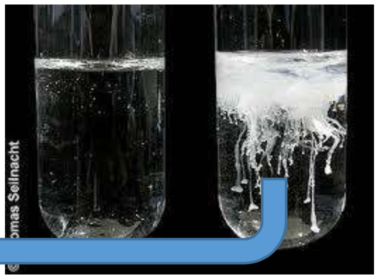
$AgNO_3$ - Solution: $Ag^+ + NO_3^-$ ions in H_2O

Really bad

$$NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$$

MISLEADING or FALSE

NaCl Solution: $Na^+ + Cl^-$ ions in H_2O



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$$Ag^+ + Cl^- \rightleftharpoons AgCl$$

$$Na^+ + Ag^+ + NO_3^- + Cl^- \rightarrow AgCl + Na^+ + NO_3^-$$

Overall reaction – NOT NEEDED

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Conversion in Chemical Reactions

Chemical reaction equations indicate how many molecules react with each other:

$$CH_4(g) + 2\ O_2(g) \rightleftharpoons CO_2(g) + 2\ H_2O(g)$$

Left-right balance

This also corresponds to the reacting amounts of substances:

$$CH_4(g) + 2\ O_2(g) \rightleftharpoons CO_2(g) + 2\ H_2O(g)$$

1 mol   2 mol   1mol   2 mol

1 mol C
4 mol H
4 mol O

From this one can also calculate the converted masses (via *M*):

$$CH_4(g) + 2\ O_2(g) \rightleftharpoons CO_2(g) + 2\ H_2O(g)$$

16.043g 63.996g   44.009g   36.030g

80.039 g

Nothing is "lost" !!

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Balancing reaction equations

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Set up the reaction equation:

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$$Fe_2O_3\,(s) + 3C\,(s) \rightleftharpoons 3\,CO_2(g) + 2Fe\,(s)$$

Example (Mortimer 4.3)

Chlorine is formed from Mn(IV) oxide and hydrogen chloride with the formation of chlorine gas, water and Mn(II) chloride

a) Write down the reaction equation.

b) How many grams of hydrogen chloride are required if 25.0 g of Mn(IV) oxide are used?

c) How many grams of chlorine gas are produced?

$$MnO_2 + HCl \rightleftharpoons Cl_2 + H_2O + MnCl_2$$

$$MnO_2 + 4\ HCl \rightleftharpoons Cl_2 + 2\ H_2O + MnCl_2$$

	MnO_2	HCl	Cl_2	H_2O	$MnCl_2$
	25.0g	??g	??g		
M_W:	86.936g	36.458g	70.90g	18.01g	125.838g
n:	0.288mol	1.15mol	0.288mol		
	25.0g	41.9g	20.4g		

$$n = \frac{m}{M}$$

$$m = n \times M$$

Note: this reaction only applies to 100% conversion.
Often only part of the product is created

Limiting Reagents

The amounts available often do NOT correspond to the stoichiometric ratios resulting from the reaction equation.

If the amount of more than one reactant is given, it must be determined which of the reactants is limiting the conversion

Example (Mortimer 4.5)

How many moles of hydrogen can theoretically be obtained from 4.00 moles of iron and 5.00 moles of water?

$$3Fe + 4H_2O \rightleftharpoons Fe_3O_4 + 4H_2$$

The limiting reagent can be determined in different ways:

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The limiting reagent can be determined in different ways:

1.) Comparison of the necessary reagents via the final calculation:

3 moles of Fe require 4 moles of H_2O; i.e. require 4.00 moles of Fe

$$n = \frac{4}{3} \times 4 = 5{,}33 \text{ mol}$$

Since there is only 5.00 moles of H_2O, H_2O is the limiting reagent.

This produces 5.00 mol H_2.

The reverse is also possible: 4 moles of water convert 3 moles of Fe. 5.00 moles of water convert 3.75 moles of Fe accordingly. There are 4.00 moles of Fe, so H_2O is the limiting reactant.

Example (Mortimer 4.5)

How many moles of hydrogen can theoretically be obtained from 4.00 moles of iron and 5.00 moles of water?

$3Fe + 4H_2O \rightleftharpoons Fe_3O_4 + 4H_2$

2.) Ratio of stoichiometric reactants:

$$\frac{n(\text{actual})}{n(\text{stoichiometric})} \qquad \frac{n(\text{Fe})}{3\text{ mol}} = \frac{4.00}{3} = 1.33 > \frac{n(\text{H}_2\text{O})}{4\text{ mol}} = \frac{5.00}{4} = 1.25$$

The smaller number indicates the limiting reagent. Accordingly, H_2O is the limiting reagent at 5.00 mol.

If the quotient is smaller, the numerator must be "too small" - i.e. the limiting reagent is in the numerator.

This produces 5.00 mol H_2.

Example

Calcium phosphide reacts with water to form monophosphane (PH_3) and calcium hydroxide.

How many g of monophosphane are formed when 10.0 g of calcium phosphide are added to 200 mL of water and the yield is 80%?

$Ca_3P_2(s) + 6\ H_2O(l) \rightleftharpoons 2\ PH_3(g) + 3\ Ca(OH)_2(aq)$

	Ca_3P_2	H_2O	PH_3	$Ca(OH)_2$
m:	10,0g	200g	?g	
M_W:	182.182g/mol	18.015 g/mol	33.998 g/mol	74.092 g/mol
n:	0.0549 mol	11.1 mol		

$$\frac{n(\text{Ca}_3\text{P}_2))}{1\text{ mol}} = \frac{0{,}0549}{1} = 0{,}0549 < \frac{n(\text{H}_2\text{O})}{6\text{ mol}} = \frac{11{,}1}{6} = 1{,}85$$

	Ca_3P_2	H_2O	PH_3
n:	0.0549 mol		0.10978 mol
80 % yield:			0.0878 mol
m:			2.99 g