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INTRODUCTION TO THE INORGANIC CHEMISTRY

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МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ РЕСПУБЛИКИ БЕЛАРУСЬ
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КАФЕДРА ОБЩЕЙ ХИМИИ

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ВВЕДЕНИЕ В НЕОРГАНИЧЕСКУЮ ХИМИЮ

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Практикум

3-е издание

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PREFACE

The book provides an introduction into the Inorganic Chemistry. It is necessary for foreign students who are going to pass the Chemistry exam into the Medical University in English.

The material from this book is enough for answering questions and solving tasks on the chemistry of elements from the entrance exam. Moreover, this book is good for students of pharmaceutical faculty who are studying «General and Inorganic Chemistry» subject.

Authors are looking forward to receive any feedback from readers and colleagues regarding style and content of the book.

LESSON 1
HYDROGEN AND WATER

1.1 HYDROGEN

Hydrogen is a unique element in the Periodic Table. 92 % of all the atoms in our Universe are hydrogen atoms (while almost 8 % of atoms are Helium atoms). There is still no agreement even about its position in the Periodic Table. Just like alkali metals, it has a single electron on its valence shell. On the other hand, hydrogen needs just a single electron to complete its valence shell, just like halogens do. That is why hydrogen can demonstrate some common chemical features with both halogens and alkali metals.

Hydrogen behaves as a reducer in reactions with the most of nonmetals (with those that have higher electronegativity than hydrogen).

$H_2 + F_2 \rightarrow 2HF$

$H_2 + Cl_2 \rightarrow 2HCl$

$H_2 + Br_2 \rightleftarrows 2HBr$

$H_2 + I_2 \rightleftarrows 2HI$

$2H_2 + O_2 \rightarrow 2H_2O$

$H_2 + S \rightleftarrows H_2S$

$3H_2 + N_2 \rightleftarrows 2NH_3$

$2H_2 + C \rightleftarrows CH_4$

At high temperature, hydrogen can reduce metals from their oxides. Actually, the term “reducer” first came from this kind of reactions: hydrogen reduces (in the direct sense) the mass of solid oxides of metals. Only those metals which are situated after zinc (including zinc itself) in the electrochemical series of metals may be produced from their oxides in the reaction with hydrogen. More active metals after the reduction will react with the excess of hydrogen and form hydrides.

$CuO + H_2 \rightarrow Cu + H_2O\uparrow$

$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O\uparrow$

Of course, hydrogen can reduce many other compounds. For example, molecular nitrogen can be produced from nitrogen oxide (II) in the reaction with hydrogen.

$2NO + 2H_2 \rightarrow N_2 + 2H_2O$

Hydrogen can also reduce iron and copper chlorides in their water solutions.

$2FeCl_3 + H_2 \rightarrow 2FeCl_2 + 2HCl$

$CuCl_2 + H_2 \rightarrow Cu\downarrow + 2HCl$

As an oxidizer hydrogen reacts with alkali and alkaline-earth metals. In those reactions hydrides of metals are produced.

$2K + H_2 \rightarrow 2KH$

$Ca + H_2 \rightarrow CaH_2$

In normal conditions hydrogen gas can react with active metals and fluorine gas only.

Hydrides easily react with water and produce alkali and molecular hydrogen.

$KH + H_2O \rightarrow KOH + H_2\uparrow$

$CaH_2 + 2H_2O \rightarrow Ca(OH)_2 + 2H_2\uparrow$

Hydrides also react with molecular oxygen. In those reactions hydroxides are produced.

$CaH_2 + O_2 \rightarrow Ca(OH)_2$

The most common reactions to produce hydrogen in laboratory are listed below.

$CaH_2 + 2H_2O \rightarrow Ca(OH)_2 + 2H_2\uparrow$

$2Al + 2NaOH + 6H_2O \rightarrow 2Na[Al(OH)_4] + 3H_2\uparrow$

$Si + 2NaOH + H_2O \rightarrow Na_2SiO_3 + 2H_2\uparrow$

$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2\uparrow$

There are also several ways to produce hydrogen in industry (at certain temperature and pressure).

$H_2O + C \rightarrow CO + H_2$

$CH_4 + H_2O \rightarrow CO + 3H_2$

$2CH_4 + O_2 \rightarrow 2CO + 4H_2$

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

However, the most common way is to perform electrolysis of pure water or sodium chloride solution.

$2H_2O\ (electrolysis) \rightarrow 2H_2\uparrow + O_2\uparrow$

$2NaCl + 2H_2O\ (electrolysis) \rightarrow 2NaOH + Cl_2\uparrow + H_2\uparrow$

1.2 WATER

The shape of water molecule is nonlinear. The angle between two bonds is equal to 104.45° (figure 1). That shape can be explained by the hypothesis of sp^3 hybridization of oxygen electron orbitals. Two of those sp^3 orbitals already contain electron pairs. Electron pairs of the oxygen atom from water molecule are able to form hydrogen bonds with hydrogen atoms of other water molecules. Finally, one molecule of water can participate in formation of four hydrogen bonds (figure 2).

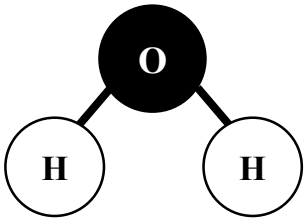


Figure 1. The shape of water molecule

Consequences of hydrogen bonds formation by water molecules are numerous: higher freezing and boiling temperatures (relative to other hydrides of nonmetals), the highest heat capacity and strong surface tension.

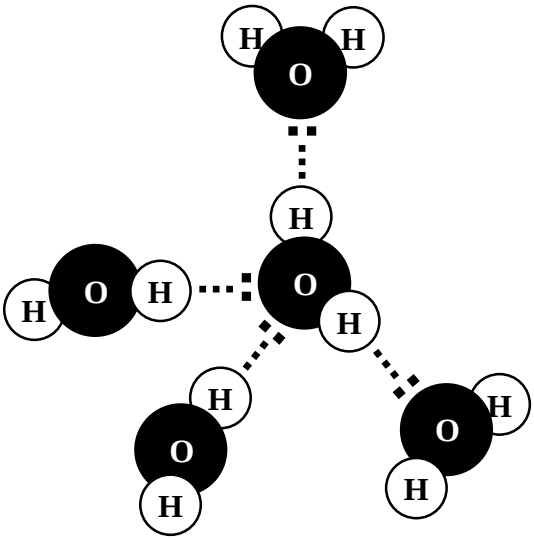


Figure 2. Formation of hydrogen bonds by water molecules

As an oxidizer water interacts with alkali metals and alkaline-earth metals.

$2K + 2H_2O \rightarrow 2KOH + H_2\uparrow$

$Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2\uparrow$

Aluminum also interacts with water in a similar way in case if protective oxide surface (Al_2O_3) has already been removed.

$2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2\uparrow$

Magnesium shows an odd behavior relative to other metals from IIA group. It reacts very slowly with a cool water. With a hot water it reacts just like other metals (except alkali and alkaline-earth ones) do.

$Mg + H_2O \rightarrow MgO + H_2\uparrow$

$Zn + H_2O \rightarrow ZnO + H_2\uparrow$

$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2\uparrow$

Only magnesium powder can interact with water and produce magnesium hydroxide.

$Mg\ (powder) + 2H_2O \rightarrow Mg(OH)_2 + H_2\uparrow$

Water cannot oxidize those metals which are situated after hydrogen in the reactivity series of metals. In contrast, water can oxidize some nonmetals presented in form of pure chemical elements (in certain conditions).

$Si + 2H_2O \rightarrow SiO_2 + 2H_2\uparrow$

$C + H_2O \rightarrow CO + H_2$

Such nonmetals as chlorine (chlorine gas) and phosphorus also react with water, while water molecules neither reduce, nor oxidize those pure chemical elements.

$Cl_2 + H_2O \rightarrow HCl + HClO$

Hydrochloric and hypochlorous acids are the products of the reaction between chlorine gas and water.

$4P + 6H_2O \rightarrow PH_3\uparrow + 3H_3PO_2$

Phosphine and hypophosphorous acid are the products of the reaction between phosphorus and water.

However, water can reduce chlorine gas being heated up.

$2Cl_2 + 2H_2O \rightarrow 4HCl + O_2$

Water hydrates both basic and acidic anhydrates to produce basic and acidic hydroxides, respectively.

$CaO + H_2O \rightarrow CaO \cdot H_2O = Ca(OH)_2$

$SO_3 + H_2O \rightarrow SO_3 \cdot H_2O = H_2SO_4$

Salts can also be hydrated by water. A salt with associated water of crystallization is known as a hydrate. Water molecules can be included in the coordination sphere of metals ($[Mn(H_2O)_4]Cl_2$), or they can be just co-crystallized with salt ($CaCl_2 \cdot 2H_2O$). In the majority of cases some water molecules are included in coordination sphere, while others are co-crystallized with salt ($[Mn(H_2O)_4]Cl_2 \cdot 2H_2O$).

Water can hydrolyze many substances, including inorganic salts, carbides and organic di- and polymeric molecules.

$Al_2S_3 + 6H_2O \rightarrow 2Al(OH)_3\downarrow + 3H_2S\uparrow$

$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2\uparrow$

EXERCISES FOR CLASSWORK

1. **Write down chemical reactions of water with the set of given substances, if they are possible:**

   CaO _____

   K _____

   $NaOH$ _____

   Cl_2 _____

   Si _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $H_2 \rightarrow H_2O \rightarrow NaOH \rightarrow H_2O \rightarrow HCl$

   1. _____

   2. _____

   3. _____

   4. _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

3. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $H_2O \rightarrow H_2SO_4 \rightarrow H_2 \rightarrow NH_3 \rightarrow NH_4Cl$

1. _____
2. _____
3. _____
4. _____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

4. **How many liters of molecular hydrogen (in form of gas) will be produced in the reaction between hydrochloric acid and 36 g of:**

potassium _____

_____

calcium _____

_____

aluminum _____

_____

5. **Calculate the mass of NaOH which is required to produce 20 L of H_2 in the reaction with**

aluminum _____

_____

silicon _____

_____

6. **Calculate the mass of water produced in the reaction between 11.2 L of hydrogen and 10 g of**

copper oxide (I) _____

_____

copper oxide (II) _____

_____

7. **Calculate the mass percentage of oxygen in**

$CuSO_4 \cdot 5H_2O$ _____

_____

$Fe_2(SO_4)_3 \cdot 5H_2O$ _____

_____

8. **Calculate the mass of water produced from 10 L of hydrogen and 20 g of copper (II) oxide.**

_____

_____

_____

9. **Calculate the mass of sulfuric acid produced in the reaction between 20 ml of sulfur (VI) oxide (density is equal to 1.92 g/ml) and 30 g of water.**

_____

_____

_____

10. **Calculate the mass of nitric acid produced in the reaction between 3 g of nitrogen (V) oxide and 20 g of water.**

_____

_____

_____

11. **What mass of $CaCl_2 \cdot 2H_2O$ should be taken to produce 100 g of 15 % $CaCl_2$ solution?**

_____

_____

_____

12. **Calculate the molarity of sodium hydroxide water solution formed after the dissolving of 2 g of sodium in 300 g of water. The density of the final solution is approximately equal to 1 g/ml.**

_____

_____

_____

13. **The mass of an alloy made from sodium and potassium was equal to 5 g. The mass percentage of sodium in that alloy was equal to 40 %. Calculate the volume of hydrogen produced after that alloy had been put into water.**

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write down chemical reactions of water with the set of given substances, if they are possible:**

   Mg _____

   HNO_3 _____

   SO_2 _____

   Al_2S_3 _____

   Au _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $KH \rightarrow KOH \rightarrow H_2O \rightarrow H_2 \rightarrow H_2S$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

3. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

$H_2O \rightarrow NaOH \rightarrow NaHCO_3 \rightarrow H_2O \rightarrow HNO_3$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

4. **How many grams of salt will be produced in the reaction between hydrochloric acid and 26 g of:**

potassium hydroxide _____

_____

calcium oxide _____

_____

iron _____

_____

5. **Calculate the mass of KOH which is required to produce 5 L of H_2 in the reaction with**

aluminum _____

_____

silicon _____

_____

6. **Calculate the mass of water produced in the reaction between 7.2 L of hydrogen and 5 g of**

iron oxide (II) _____

_____

iron oxide (III) _____

_____

7. **Calculate the mass percentage of water in**
   $CuSO_4 \cdot 5H_2O$ _____
   _____
   $CaCl_2 \cdot 2H_2O$_____
   _____

8. **Calculate the mass of water produced from 5 L of hydrogen and 10 g of tin (II) oxide.**
   _____
   _____
   _____

9. **Calculate the mass of barium hydroxide produced in the reaction between 8 g of barium oxide and 20 g of water.**
   _____
   _____
   _____

10. **Calculate the mass of calcium hydroxide produced in the reaction between 5 g of calcium and 30 g of water.**
    _____
    _____
    _____

11. **What mass of $Na_2SO_4 \cdot 10H_2O$ should be taken to produce 300 g of 5 % Na_2SO_4 solution?**
    _____
    _____
    _____

12. **Calculate the molarity of orthophosphoric acid water solution formed after the dissolving of 2 g of phosphorus (V) oxide in 200 g of water at high temperature. The density of the final solution is approximately equal to 1 g/ml.**
    _____
    _____
    _____

13. **The mass of a mixture made from magnesium oxide and calcium oxide was equal to 7 g. The mass percentage of magnesium oxide in that mixture was equal to 65 %. Calculate the mass of water reacted with that mixture at room temperature.**
    _____
    _____
    _____

LESSON 2
HALOGENS AND THEIR COMPOUNDS

2.1 HALOGENS

The halogens or halogen elements are the 17th (VIIA) group in the periodic table consisting of five chemically related elements: fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At). The group of halogens is the only periodic table group which contains elements in all three familiar states of matter at standard temperature and pressure: fluorine (F_2) and chlorine (Cl_2) are gases, bromine (Br_2) is liquid, while iodine (I_2) is solid. Astatine is thought to be solid.

Halogens react with hydrogen and form diatomic molecules which demonstrate acidic properties in water solutions.

$H_2 + Cl_2 \rightarrow 2HCl$

At room temperature halogens (except fluorine) react with water and produce two acids: hydrochloric acid (HCl) and hypochlorous acid (HClO) in case of chlorine (figure 3, *a*).

$Cl_2 + H_2O \rightarrow HCl + HClO$

Resulting solution can be used as a disinfectant or bleach.

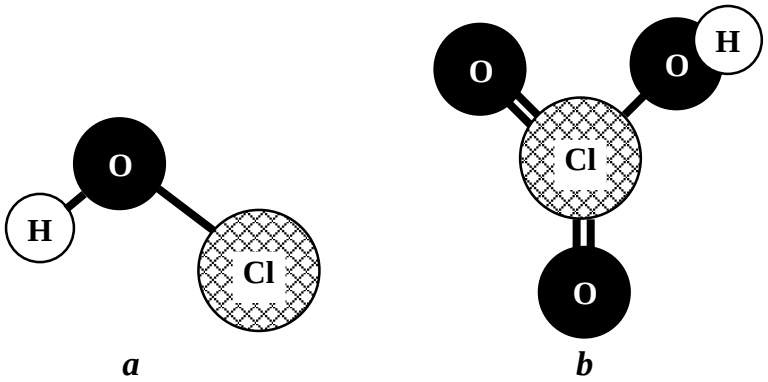


Figure 3. Structures of HClO (hypochlorous) and $HClO_3$ (chloric) acids

Hydrochlorous acid is instable: it spontaneously forms hydrochloric acid and atomic oxygen, which is a free radical able to oxidize many substances including proteins of pathogenic bacteria.

At higher temperature the mixture of hydrochloric acid HCl and chloric acid ($HClO_3$) is formed (figure 3, *b*).

$3Cl_2 + 3H_2O \rightarrow 5HCl + HClO_3$

Bromine slowly reacts with water to form hydrogen bromide (HBr) and hypobromous acid (HBrO), while iodine is minimally soluble in water and does not react with it. However, iodine will form an aqueous solution in the presence of iodide ion, such as by addition of potassium iodide (KI), because the triiodide ion ($I_2 + I^- \rightarrow I_3^-$) is formed.

Halogens oxidize metals and produce salts.

$2Na + I_2 \rightarrow 2NaI$

$2Fe + 3Cl_2 \rightarrow 2FeCl_3$

A halogen with lower atomic number is able to oxidize anions of halogens with higher atomic numbers, and not vice versa.

$Cl_2 + 2KBr \rightarrow 2KCl + Br_2$

$Br_2 + 2KCl \neq$

$Cl_2 + 2NaI \rightarrow 2NaCl + I_2$

$I_2 + 2NaCl \neq$

$Br_2 + 2KI \rightarrow 2KBr + I_2$

$I_2 + 2KBr \neq$

Hydrogen chloride can be produced from solid chlorides of metals in the reaction with concentrated sulfuric acid, unlike hydrogen bromide and iodide. HBr and HI are easily oxidized by concentrated sulfuric acid. At room temperature hydrogen sulfate of sodium (acidic salt) will be formed, while at high temperature sodium sulfate will be the product of this process. In both cases sodium chloride must be solid.

$NaCl(solid) + H_2SO_4(concentrated) \rightarrow NaHSO_4 + HCl\uparrow$

$2NaCl(solid) + H_2SO_4(concentrated) \rightarrow Na_2SO_4 + 2HCl\uparrow$

$2NaBr(solid) + 2H_2SO_4(concentrated) \rightarrow Na_2SO_4 + SO_2\uparrow + Br_2 + 2H_2O$

Chlorine gas can be produced in laboratory from hydrochloric acid in the reaction with an oxidizer (for example, with manganese oxide (IV) or potassium permanganate).

$MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2\uparrow + 2H_2O$

$2KMnO_4 + 16HCl \rightarrow 2MnCl_2 + 5Cl_2\uparrow + 2KCl + 8H_2O$

Potassium iodide is a strong reducer. Aged and impure samples of that salt are yellow because of aerial oxidation of iodide to elemental iodine.

$4KI + 2CO_2 + O_2 \rightarrow 2K_2CO_3 + 2I_2$

Chlorine gas reacts with alkali and produces different sets of salts depending on the temperature.

$Cl_2 + 2KOH \rightarrow KCl + KClO + H_2O$ (when the temperature is low)

$3Cl_2 + 6KOH \rightarrow 5KCl + KClO_3 + 3H_2O$ (when the temperature is high)

Potassium iodate (KlO_3) which is sometimes used for iodination of table salt can be produced in a similar reaction.

$3l_2 + 6KOH \rightarrow 5Kl + KlO_3 + 3H_2O$

2.2 HYDROCHLORIC ACID

Hydrogen chloride in normal conditions exists as a gas. The bond between hydrogen and chlorine is covalent polar, but not ionic. When hydrogen chloride is being dissolved in water the bond between hydrogen and chlorine becomes more polar and finally hydrogen chloride molecule breaks in two ions (H^+ and Cl^-). Resulting water solution is called «hydrochloric acid». In Russian hydrochloric acid has a trivial name which can be translated into English as «salty acid». That name came from the reaction of HCl formation from the table salt (NaCl).

$2NaCl(solid) + H_2SO_4(concentrated) \rightarrow Na_2SO_4 + 2HCl\uparrow$

Hydrochloric acid demonstrates all the common properties of acids. It reacts with alkali and basic oxides to produce salts and water.

$HCl + KOH \rightarrow KCl + H_2O$

$2HCl + K_2O \rightarrow 2KCl + H_2O$

Hydrochloric acid reacts with metals situated before hydrogen in the reactivity series.

$Zn + 2HCl \rightarrow ZnCl_2 + H_2\uparrow$

$Cu + HCl \neq$

Reaction between hydrochloric acid and salt proceeds to the end in case if insoluble salt or gas is produced.

$HCl + AgNO_3 \rightarrow AgCl\downarrow + HNO_3$

$2HCl + CaSO_3 \rightarrow CaCl_2 + SO_2\uparrow + H_2O$

The presence of Cl^- ions in the solution can be checked by the addition of Ag^+ ions ($AgNO_3$ solution is used since it is one of the very few soluble salts of silver). AgCl is a white precipitate. Bromine and iodide anions also form precipitates with Ag^+, but of a different color (AgBr is light yellow, while AgI is yellow).

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

$LiBr + AgNO_3 \rightarrow LiNO_3 + AgBr\downarrow$

$KI + AgNO_3 \rightarrow KNO_3 + AgI\downarrow$

TEST FOR CLASSWORK

1. In which reactions hydrogen atoms act as reducers?
   a) $H_2 + Cl_2 \rightarrow 2HCl$
   b) $2K + H_2 \rightarrow 2KH$
   c) $CuCl_2 + H_2 \rightarrow Cu + 2HCl$
   d) $3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2$
2. In which reactions hydrogen atoms act as oxidizers?
   a) $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$
   b) $2CH_4 + O_2 \rightarrow 2CO + 4H_2$
   c) $2Na + 2H_2O \rightarrow 2NaOH + H_2$
   d) $3H_2 + N_2 \rightarrow 2NH_3$
3. In which reactions hydrogen gas is released?
   a) $H_2O + K \rightarrow$
   b) $HCl + Zn \rightarrow$
   c) $H_2SO_4 + Cu \rightarrow$
   d) $HNO_3 + Fe \rightarrow$
4. Choose ions represented as H^+ in ionic equations:
   a) H_3O^+ b) $H_3O_2^-$ c) $H_5O_2^+$ d) OH^-
5. Bromine (Br_2) in normal conditions is a:
   a) gas b) liquid c) solid substance d) plasma

6. Which substance is used in qualitative analysis of solutions for the presence of anions of halogens?
   a) $NaNO_3$ b) H_2SO_4 c) $AgNO_3$ d) KOH
7. Which reactions are possible?
   a) $KI + Cl_2 \rightarrow$
   b) $KBr + I_2 \rightarrow$
   c) $NaBr + Cl_2 \rightarrow$
   d) $NaCl + I_2 \rightarrow$
8. Calculate the sum of all coefficients in the redox reaction:
   $LiOH + Cl_2\ (t°) \rightarrow LiCl + LiClO_3 + H_2O$
   a) 9 b) 10 c) 17 d) 18
9. Which reactions can be expressed by the ionic equation: $Ca + 2H^+ \rightarrow Ca^{2+} + H_2$
   a) $Ca + 2HF \rightarrow CaF_2 + H_2$
   b) $Ca + 2HCl \rightarrow CaCl_2 + H_2$
   c) $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$
   d) $Ca + H_2 \rightarrow CaH_2$
10. Choose formulas of hydrates:
    a) BaH_2 b) NaOH c) $CuSO_4 \cdot 5H_2O$ d) $H_2C_2O_4 \cdot 2H_2O$

TEST FOR HOMEWORK

1. In which reactions chlorine atoms act as oxidizers?
   a) $KOH + HCl \rightarrow KCl + H_2O$
   b) $3Cl_2 + 2P \rightarrow 2PCl_3$
   c) $KCl + AgNO_3 \rightarrow KNO_3 + AgCl$
   d) $3Cl_2 + 2Fe \rightarrow 2FeCl_3$
2. In which reactions iodine atoms act as reducers?
   a) $2KI + Cl_2 \rightarrow 2KCl + I_2$
   b) $I_2 + H_2 \rightarrow 2HI$
   c) $2Na + I_2 \rightarrow 2NaI$
   d) $6KI + 2KMnO_4 + 4H_2O \rightarrow 3I_2 + 2MnO_2 + 8KOH$
3. In which reactions chlorine gas is released?
   a) $MnO_2 + HCl \rightarrow$ c) $BaCl_2 + H_2SO_4 \rightarrow$
   b) $KMnO_4 + HCl \rightarrow$ d) $FeCl_3 + H_2O \rightarrow$
4. Choose ions formed in water solution of I_2 in the presence of KI:
   a) I_3^- b) I_2^- c) I_3^{3-} d) I_2^{2-}
5. Iodine (I_2) in normal conditions is a:
   a) gas b) liquid c) solid substance d) plasma

6. Indicate the colors of AgCl, AgBr and AgI:
   a) white / yellow / red
   b) white / pale yellow / yellow
   c) yellow / pale yellow / white
   d) red / yellow / white

7. Which reactions are possible?
   a) $NaBr + Cl_2 \rightarrow$
   b) $NaBr + I_2 \rightarrow$
   c) $HBr + Cl_2 \rightarrow$
   d) $NaCl + I_2 \rightarrow$

8. Calculate the sum of all coefficients in the redox reaction: $KI + CO_2 + O_2 \rightarrow K_2CO_3 + I_2$
   a) 11 b) 10 c) 9 d) 8

9. Which reactions can be expressed by the ionic equation: $2Br^- + Cl_2 \rightarrow 2Cl^- + Br_2$
   a) $2AgBr + CaCl_2 \rightarrow CaBr_2 + 2AgCl$
   b) $2HBr + Cl_2 \rightarrow 2HCl + Br_2$
   c) $2NaBr + CaCl_2 \rightarrow CaBr_2 + 2NaCl$
   d) $2KBr + Cl_2 \rightarrow 2KCl + Br_2$

10. Choose formulas of hydrides:
    a) CaH_2 b) LiH c) $FeSO_4 \cdot 5H_2O$ d) $H_2C_2O_4$

EXERCISES FOR CLASSWORK

1. Write four reactions according to the following classic chain of chemical reactions and balance them:

$NaCl \rightarrow Cl_2 \rightarrow FeCl_3 \rightarrow KCl \rightarrow AgCl$

1. _____
2. _____
3. _____
4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

2. Write four reactions according to the following classic chain of chemical reactions and balance them:

$K \rightarrow KI \rightarrow KBr \rightarrow KCl \rightarrow KNO_3$

1. _____

2. _____
3. _____
4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

3. **Determine the mass of potassium iodide (KI) produced from 1 kg of molecular iodine in its reaction with potassium hydroxide at high temperature.**

_____

_____

_____

4. **Calculate the volume of hydrogen chloride that can be produced from 100 g of solid sodium chloride with the help of concentrated sulfuric acid at high temperature.**

_____

_____

_____

5. **Mass percentages of calcium, bromine and oxygen in the compound are equal to 13.5 %, 54.0 % and 32.4 %, respectively. Determine the simplest formula of that compound.**

_____

_____

_____

6. **Find out the simplest formula of a compound. The mass percentages of elements in the compound are as follows: 44.83 % of potassium, 18.39 % of sulfur and 36.78 % of oxygen.**

_____

_____

_____

7. **Find out the simplest formula of a substance if in 200 g of it there are 80 g of calcium, 24 g of carbon and 96 g of oxygen.**

_____

_____

_____

_____

8. **Hydrogen chloride has been produced in the reaction between 29.25 g of solid sodium chloride and an excess of concentrated sulfuric acid. Then hydrogen chloride has been dissolved in 73 g of water. Determine the mass percentage of HCl in the hydrochloric acid solution.**

_____

_____

_____

_____

9. **The mass of the mixture made from iron and copper is 15 g. That mixture reacted with 7.75 L of chlorine gas. Find the mass percentage of copper in the initial mixture.**

_____

_____

_____

_____

10. **100 g of hydrochloric acid with the mass percentage of 3 % has been added to the solution containing 2 g of sodium hydroxide and 2.5 g of potassium hydroxide. Then 2 ml of silver nitrate solution with the molar concentration of 0.01 M has been added to the resulting solution. Find the mass of a precipitate.**

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $Br_2 \rightarrow ZnBr_2 \rightarrow NaBr \rightarrow Br_2 \rightarrow KBrO_3$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the first reaction in the complete and short ionic forms:

   _____

   _____

   Write the second reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $F_2 \rightarrow HF \rightarrow NiF_2 \rightarrow ZnF_2 \rightarrow CaF_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the second reaction in the complete and short ionic forms:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

3. **Determine the mass of potassium iodide (KI) produced from 1 kg of molecular iodine in its reaction with pure potassium.**

   _____

   _____

   _____

4. **Calculate the mass of 5 % hydrochloric acid that can be produced from 100 g of solid potassium chloride with the help of concentrated sulfuric acid at room temperature.**

   _____

   _____

   _____

5. **Mass percentages of potassium, chlorine and oxygen in the compound are equal to 32 %, 29 % and 39 %, respectively. Determine the simplest formula of that compound.**

   _____

   _____

   _____

6. **Find out the simplest formula of a compound. The mass percentages of elements in the compound are as follows: 18.78 % of sodium, 28.98 % of chlorine and 52.24 % of oxygen.**

   _____

   _____

   _____

7. **Find out the simplest formula of a substance if in 699 g of it there are 411 g of barium, 96 g of sulfur and 192 g of oxygen.**

_____

_____

_____

8. **Chlorine gas produced in the reaction between manganese oxide (IV) and 36 % hydrochloric acid (density is equal to 1.18 g/ml) oxidized iodide ions in potassium iodide. Determine the volume of the initial hydrochloric acid solution if the mass of molecular iodine was equal to 25.4 g.**

_____

_____

_____

9. **The mass of the mixture made from iron and copper is 30 g. That mixture reacted with hydrochloric acid and produced 0.5 L of hydrogen. Find the mass percentage of copper in the initial mixture.**

_____

_____

_____

10. **200 g of hydroiodic acid with the mass percentage of 2 % has been added to the solution containing 1 g of sodium iodide and 0.5 g of potassium iodide. Then 5 ml of silver nitrate solution with the molar concentration of 0.05 M has been added to the resulting solution. Find the mass of a precipitate.**

_____

_____

_____

_____

LESSON 3
OXYGEN AND ITS COMPOUNDS

3.1 OXYGEN AND OZONE

Oxygen as a pure chemical element exists in two allotropic modifications: oxygen gas (O_2) and ozone (O_3).

The common allotrope of elemental oxygen on Earth is called dioxygen, O_2. This is the form that is used by complex forms of life, such as animals, in cellular respiration and is the form that is an important part of the Earth's atmosphere.

Ozone (Trioxygen, O_3) is a very reactive allotrope of oxygen that is damaging to lung tissue. It demonstrates higher reactivity than oxygen and can even react with such inactive metals as gold and platinum.

Ozone is produced in the upper atmosphere when O_2 combines with atomic oxygen made by the splitting of O_2 by ultraviolet (UV) radiation. Since ozone absorbs strongly in the UV region of the spectrum, the ozone layer of the upper atmosphere functions as a protective radiation shield for the planet.

The molecule of ozone is polar (see the structure of ozone molecule shown in figure 4), unlike the molecule of oxygen.

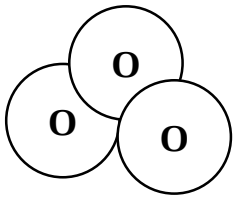


Figure 4. Structure of ozone

3.2 OXYGEN CONTAINING COMPOUNDS

Oxygen is able to form three types of compounds with alkali metals: oxides, peroxides and superoxides.

In oxides the oxidation state of oxygen is equal to –2, as well as in the most of oxygen compounds.

$4Na + O_2 \rightarrow 2Na_2O$

In peroxides oxygen atoms have the oxidation state of –1.

$2Na + O_2 \rightarrow Na_2O_2$

In superoxides oxygen demonstrates fractional oxidation state of $-^1/_2$. Actually, superoxide is a compound that contains the superoxide anion with the chemical formula O_2^-.

$K + O_2 \rightarrow KO_2$

In fact, a mixture of oxide and peroxide is formed after the reaction between sodium and oxygen, but peroxide prevails. In the reaction between oxygen and potassium the mixture of peroxide and superoxide is formed, but superoxide prevails.

Superoxides of alkali metals can react with those metals to produce peroxides.

$KO_2 + K \rightarrow K_2O_2$

Peroxides of alkali metals can react with those metals to produce oxides.

$Na_2O_2 + 2Na \rightarrow 2Na_2O$

Peroxides react with water. Oxygen is produced in that kind of reactions.

$2Na_2O_2 + 2H_2O \rightarrow 4NaOH + O_2\uparrow$

If chemical compounds are burnt in the excess of oxygen, a mixture of oxides is produced.

$2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$

$2CuS + 3O_2 \rightarrow 2CuO + 2SO_2$

$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

If chemical compounds are burnt in conditions with the limited amount of oxygen, some pure chemical elements may be produced.

$2H_2S + O_2 \rightarrow 2S + 2H_2O$

$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$

Oxygen can be produced in laboratory in several decomposition reactions.

$2KMnO_4 \rightarrow K_2MnO_4 + MnO_2 + O_2\uparrow$

$2KClO_3 \rightarrow 2KCl + 3O_2\uparrow$

$2KNO_3 \rightarrow 2KNO_2 + O_2\uparrow$

$2H_2O_2 \rightarrow 2H_2O + O_2\uparrow$

EXERCISES FOR CLASSWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $O_2 \rightarrow Na_2O_2 \rightarrow Na_2O \rightarrow NaNO_3 \rightarrow O_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $O_3 \rightarrow O_2 \rightarrow Na_2O_2 \rightarrow H_2O_2 \rightarrow O_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the kinetic equation for the first reaction, and the equation for the constant of equilibrium for that process:

   _____

   _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

3. **Write the oxidation state of oxygen upon the formulas of the following compounds: H_2O, H_2O_2, O_2, Na_2O, Na_2O_2, KO_2, F_2O_2, F_2O.**

4. **Determine the volume of oxygen produced in the decomposition reaction: from 10 g of potassium permanganate ($KMnO_4$)**

   _____

   _____

   from 6 g of potassium chlorate ($KClO_3$)

   _____

   _____

5. **Calculate the volume of ozone that can be produced from 100 L of oxygen.**

   _____

   _____

6. **What is the density of ozone per dry air?**

   _____

   _____

7. **Calculate the volume of oxygen needed to burn 10 g of potassium. Consider potassium superoxide as the only one product of this reaction.**

   _____

   _____

   _____

   _____

8. **What is the mass percentage of copper (II) sulfide that has really been burnt in the reaction with the excess of oxygen if the volume of sulfur (IV) oxide is equal to 12 L? In the beginning of the reaction there were 100 g of copper (II) sulfide.**

_____

_____

_____

9. **Find the volume percentage of methane in its mixture with carbon dioxide. 30 L of that mixture reacted with 30 L of oxygen (in normal conditions).**

_____

_____

_____

10. **The mass of oxygen atoms in the sample of barium sulfate is equal to 11.7 g. Find out the mass of the whole sample.**

_____

_____

_____

_____

11. **The mass of the mixture made from gold and zinc is 130 g. That mixture has been burnt. The mass of the resulting mixture is equal to 140 g. Find the mass percentage of gold in the initial mixture.**

_____

_____

_____

_____

12. **The volume fraction of ozone in its mixture with oxygen is equal to 25 %. Determine the volume of that mixture that is enough to burn down completely 20 L of another mixture that is made from ethane and propane. In the last one the volume percentage of ethane is 50 %.**

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $O_2 \rightarrow SO_2 \rightarrow Na_2SO_3 \rightarrow BaSO_3 \rightarrow SO_2$

   1. _____

2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write the third reaction in the complete and short ionic forms:

_____

_____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

$O_2 \rightarrow KO_2 \rightarrow K_2O_2 \rightarrow KOH \rightarrow KBr$

1. _____
2. _____
3. _____
4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

3. **Write the oxidation state of oxygen upon the formulas of the following particles: H_3O^+, BaO_2, O_3, Na_2CO_3, CO_3^{2-}, FeO^+, OH^-, C_2H_5OH.**
4. **Determine the volume of oxygen produced in the decomposition reaction: from 15 g of potassium nitrate (KNO_3)**

_____

_____

from 8 g of hydrogen peroxide (H_2O_2)

_____

_____

5. **Calculate the volume of oxygen that can be produced from 100 L of ozone.**

_____

_____

6. **What is the density of oxygen per dry air?**

_____

_____

7. **Calculate the volume of oxygen needed to burn 3 g of sodium. Consider sodium peroxide as the only one product of this reaction.**

_____

_____

_____

8. **What is the mass percentage of copper (II) sulfide that has really been burnt in the reaction with oxygen if the mass of copper (II) oxide is equal to 20 g? In the beginning of the reaction there were 40 g of copper sulfide.**

_____

_____

_____

9. **Find the volume percentage of acetylene in its mixture with nitrogen. 20 L of that mixture reacted with 7 L of oxygen (in normal conditions).**

_____

_____

_____

10. **The mass of oxygen atoms in the sample of copper sulfate pentahydrate is equal to 21.7 g. Find out the mass of the whole sample.**

_____

_____

_____

11. **The mass of the mixture made from platinum and aluminum is 25 g. That mixture has been burnt. The mass of the resulting mixture is equal to 30 g. Find the mass percentage of platinum in the initial mixture.**

_____

_____

_____

_____

12. **The volume fraction of ozone in its mixture with oxygen is equal to 30 %. Determine the volume of that mixture that is enough to burn down completely 10 L of another mixture that is made from methane and acetylene. In the last one the volume percentage of methane is 20 %.**

_____

_____

_____

_____

LESSON 4
SULFUR AND ITS COMPOUNDS

4.1 SULFUR

Sulfur is a solid substance in normal conditions. Sulfur forms polyatomic molecules with different chemical formulas, with the best-known allotrope being octasulfur, cyclo-S_8 (figure 5). Sulfur forms over 30 solid allotropes, more than any other element.

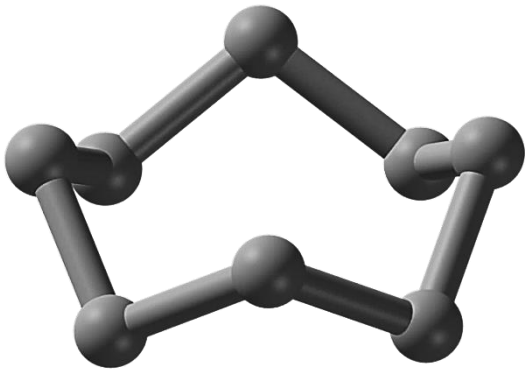


Figure 5. Structure of S_8 molecule

Sulfur can be produced in industry in the reaction between hydrogen sulfide and sulfur (IV) oxide.

$2H_2S + SO_2 \rightarrow 2H_2O + 3S$

In the laboratory sulfur can be produced in several ways.

$FeS_2 \rightarrow FeS + S$

$2H_2S + O_2 \rightarrow 2S + 2H_2O$

$SO_2 + C \rightarrow CO_2 + S\downarrow$

$H_2S + Cl_2 \rightarrow 2HCl + S\downarrow$

Diatomic compounds of sulfur and metals are known as sulfides. Sulfur demonstrates oxidation state of –2 in those salts.

$2K + S \rightarrow K_2S$

$Cu + S \rightarrow CuS$

However, in pyrite (FeS_2, also known as «fool's gold») sulfur demonstrates the oxidation state of –1.

Sulfur forms SO_2 in the reaction with oxygen. Sulfuric acid anhydrate (SO_3) may be produced in the reaction between SO_2 and O_2 in the presence of a catalyst only.

$S + O_2 \rightarrow SO_2$

$2SO_2 + O_2 \rightleftarrows 2SO_3$

Sulfur can directly interact with alkali and certain acids.

$3S + 6KOH \rightarrow K_2SO_3 + 2K_2S + 3H_2O$

$S + 2H_2SO_4(\text{concentrated}) \rightarrow 3SO_2\uparrow + 2H_2O$

$S + 4HNO_3(\text{concentrated}) \rightarrow 4NO_2\uparrow + SO_2\uparrow + 2H_2O$

4.2 COMPOUNDS OF SULFUR

Hydrogen sulfide in normal conditions is a colorless gas with the characteristic foul odor of rotten eggs. Water solution of H_2S demonstrates acidic properties. Best way to produce H_2S in laboratory is the reaction between soluble sulfide and hydrochloric acid.

$Na_2S + 2HCl \rightarrow 2NaCl + H_2S\uparrow$

$K_2S + 2HCl \rightarrow 2KCl + H_2S\uparrow$

It is also known that aluminum sulfide undergoes complete hydrolysis and produces aluminum hydroxide and hydrogen sulfide.

$Al_2S_3 + 6H_2O \rightarrow 2Al(OH)_3\downarrow + 3H_2S\uparrow$

Sulfides of metals are good reducers (just like hydrogen sulfide).

$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2\uparrow$

$3CuS + 8HNO_3(\text{concentrated}) \rightarrow 3CuSO_4 + 8NO\uparrow + 4H_2O$

Soluble sulfides are partially hydrolyzed in water solutions.

$K_2S + H_2O \rightleftarrows KHS + KOH$

Sulfurous acid anhydrate (also known as sulfur (IV) oxide) demonstrates all the features of acidic oxide. Moreover, it can behave as oxidizer or reducer. Some specific reactions are listed below.

$SO_2 + Na_2CO_3(\text{concentrated}) \rightarrow Na_2SO_3 + CO_2\uparrow$

$SO_2 + 2CO \rightarrow S + 2CO_2\uparrow$

$SO_2 + Br_2 + 2H_2O \rightarrow H_2SO_4 + 2HBr$

$SO_2 + 2HNO_3(\text{concentrated}) \rightarrow H_2SO_4 + 2NO_2\uparrow$

Sulfurous acid produced in reactions between sulfites (salts of sulfurous acid) and other acids decomposes into SO_2 and H_2O.

$Na_2SO_3 + H_2SO_4 \rightarrow Na_2SO_4 + SO_2\uparrow + H_2O$

Sulfurous acid and its salts participate in some specific redox reactions. There are some examples.

$2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$

$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$

$H_2SO_3 + Br_2 + H_2O \rightarrow H_2SO_4 + 2HBr$

$H_2SO_3 + 2H_2S \rightarrow 3S + 3H_2O$

$4K_2SO_3 \rightarrow K_2S + 3K_2SO_4$

Sulfuric acid anhydrate (sulfur (VI) oxide) demonstrates common properties of acidic oxide. SO_3 is also a strong oxidizer.

$5SO_3 + 2P \rightarrow 5SO_2\uparrow + P_2O_5$

$3SO_3 + H_2S \rightarrow 4SO_2 + H_2O$

Industrial method of sulfuric acid production includes four steps.

1. $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$ (oxidation of pyrite)
2. $2SO_2 + O_2 \rightarrow 2SO_3$ (oxidation of sulfur (IV) oxide in the presence of a catalyst)

3. $SO_3 + H_2SO_4$(concentrated) → $H_2SO_4 \cdot SO_3 = H_2S_2O_7$ (concentrated sulfuric acid interacts with sulfur (VI) oxide and produces so-called oleum also known as «fuming sulfuric acid»)

4. $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$ (oleum is then diluted by water to produce H_2SO_4 of the needed concentration)

Diluted sulfuric acid (mass percentage is lower than 20 %) demonstrates all the common features of acids. Remember than diluted (and not concentrated) sulfuric acid interacts with metals and produces hydrogen gas.

$Fe + H_2SO_4$(diluted) → $FeSO_4 + H_2\uparrow$

Concentrated sulfuric acid (mass percentage is equal to 93–98 %) reacts with all metals (except aluminum, iron and chrome at low temperature, and gold and platinum at any temperature) and produces sulfur (IV) oxide. It is important to mention that concentrated sulfuric acid is a weak electrolyte and exists in form of molecules (figure 6). For this reason, sulfur atoms themselves act as oxidizers when sulfuric acid is concentrated. In contrast, in diluted sulfuric acid hydrogen atoms act as oxidizers (just like in case with the most of other acids).

$Zn + 2H_2SO_4$(concentrated) → $ZnSO_4 + SO_2\uparrow + 2H_2O$

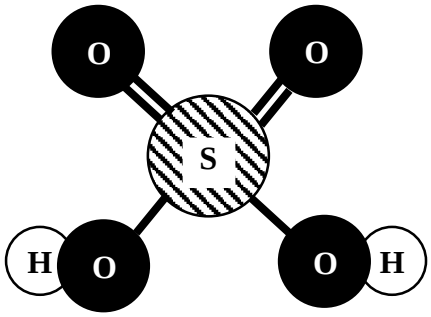


Figure 6. Structure of sulfuric acid molecule

Sulfuric acid of average concentrations can react with metals of an average activity and produce a variety of products.

$3Zn + 4H_2SO_4$(50 %) → $3ZnSO_4 + S\downarrow + 4H_2O$

$4Zn + 5H_2SO_4$(30 %) → $4ZnSO_4 + H_2S\uparrow + 4H_2O$

Concentrated sulfuric acid can oxidize not only metals but nonmetals as well.

$2P + 5H_2SO_4$(concentrated) → $2H_3PO_4 + 5SO_2\uparrow + 2H_2O$

$C + 2H_2SO_4$(concentrated) → $CO_2\uparrow + 2SO_2\uparrow + 2H_2O$

Concentrated sulfuric acid is used to produce acids from their solid salts.

$2KNO_3$(solid) + H_2SO_4(concentrated) → $K_2SO_4 + 2HNO_3\uparrow$

Sulfates (salts of sulfuric acid) can be decomposed into metal oxide and sulfur (VI) oxide, or into metal oxide, sulfur (IV) oxide and oxygen gas. The later reaction takes place at higher temperature than the first one: SO_3 decomposes into SO_2 and O_2.

$CuSO_4 \rightarrow CuO + SO_3\uparrow$

$2CuSO_4 \rightarrow 2CuO + 2SO_2\uparrow + O_2\uparrow$

Soluble sulfates are recognized in their solutions in the following way. Addition of barium chloride results in formation of white precipitate $BaSO_4$.

$Na_2SO_4 + BaCl_2 \rightarrow 2NaCl + BaSO_4\downarrow$

TEST FOR CLASSWORK

1. Choose formulas of oxides:
   a) H_2O b) H_2O_2 c) BaO d) BaO_2
2. Choose formulas of peroxides:
   a) K_2O b) K_2O_2 c) KO_2 d) CaO_2
3. Choose formulas of superoxides:
   a) Na_2O b) NaO_2 c) PbO_2 d) KO_2
4. Oxygen will be released in reactions:
   a) $Na + H_2O \rightarrow$ c) $KClO_3$ (t°) $\rightarrow$
   b) $NaNO_3$ (t°) $\rightarrow$ d) $CaCO_3$ (t°) $\rightarrow$
5. In which reactions sulfur atoms act as reducers:
   a) $Na_2S + 2HCl \rightarrow 2NaCl + H_2S$
   b) $2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$
   c) $2H_2S + O_2 \rightarrow 2S + 2H_2O$
   d) $Cu + S \rightarrow CuS$
6. Choose substances which react with concentrated H_2SO_4:
   a) NaCl (solid) b) KCl (water solution) c) Ag d) Au
7. Which reactions are possible?
   a) $Fe + H_2SO_4$ (dilute) $\rightarrow$
   b) $Fe + H_2SO_4$ (concentrated / low temperature) $\rightarrow$
   c) $Al + H_2SO_4$ (concentrated / high temperature) $\rightarrow$
   d) $Pt + H_2SO_4 \rightarrow$
8. Calculate the sum of all coefficients in the redox reaction:
   $C + H_2SO_4$ (concentrated) $\rightarrow CO_2 + SO_2 + H_2O$
   a) 5 b) 6 c) 7 d) 8
9. Which reactions can be expressed by the following ionic equation:
   $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$
   a) $BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2HCl$
   b) $Ba + H_2SO_4 \rightarrow BaSO_4 + H_2$
   c) $Ba(NO_3)_2 + K_2SO_4 \rightarrow BaSO_4 + 2KNO_3$
   d) $Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4 + 2H_2O$

10. Choose formulas of sulfites:
    a) BaS b) K_2S c) K_2SO_3 d) Na_2SO_3

TEST FOR HOMEWORK

1. Choose formula of iron sulfide used in industrial sulfuric acid production:
    a) FeS b) Fe_2S_3 c) FeS_2 d) Fe_3S_4
2. Choose correct statements about hydrogen sulfide (H_2S):
    a) it has an odor of rotten eggs
    b) it is solid in normal conditions
    c) it is weak electrolyte in water solution
    d) its water solution is acidic
3. Choose substances which cannot react with dilute sulfuric acid (H_2SO_4):
    a) NaOH b) NaCl $_{(solid)}$ c) Cu d) CuO
4. Oxygen will be released in reactions:
    a) H_2O_2 (t°) → c) NaOH (t°) →
    b) $AgNO_3$ (t°) → d) $Ca(OH)_2$ (t°) →
5. In which reactions sulfur atoms act as oxidizers:
    a) $SO_2 + C \rightarrow CO_2 + S$
    b) $2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$
    c) $5SO_3 + 2P \rightarrow 5SO_2 + P_2O_5$
    d) $Mg + S \rightarrow MgS$
6. Choose substances which react with concentrated H_2SO_4:
    a) $BaCl_2$ $_{(solid)}$ b) $BaCl_2$ $_{(water\ solution)}$ c) Pt d) P
7. Which reactions are possible?
    a) $FeSO_3 + H_2SO_4 \rightarrow$ c) $C + H_2SO_4 \rightarrow$
    b) $Al_2S_3 + H_2O \rightarrow$ d) $Na_2SO_4 + K_2S \rightarrow$
8. Calculate the sum of all coefficients in the redox reaction:
    $S + H_2SO_4$ $_{(concentrated)}$ $\rightarrow SO_2 + H_2O$
    a) 5 b) 6 c) 7 d) 8
9. Which reactions can be expressed by the following ionic equation: $2H^+ + S^{2-} \rightarrow H_2S$
    a) $2HCl + K_2S \rightarrow 2KCl + H_2S$
    b) $H_2SO_4 + BaS \rightarrow BaSO_4 + H_2S$
    c) $2HNO_3 + Na_2S \rightarrow 2NaNO_3 + H_2S$
    d) $H_2 + S \rightarrow H_2S$
10. Choose formulas of sulfides:
    a) ZnS b) Na_2S c) K_2S d) Na_2SO_3

EXERCISES FOR CLASSWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $S \rightarrow SO_2 \rightarrow SO_3 \rightarrow ZnSO_4 \rightarrow K_2SO_4$

   1. _____
   2. _____
   3. _____
   4. _____

   Write electron balance for the second reaction:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $CuS \rightarrow SO_2 \rightarrow S \rightarrow H_2S \rightarrow CoS$

   1. _____
   2. _____
   3. _____
   4. _____

   Write kinetic equation for the third reaction, and the equation for the constant of equilibrium for that process:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

3. **What is the mass of sulfur in 10 kg of:**

   FeS _____

   Fe_2S_3 _____

   FeS_2 _____

4. **Calculate the volume (in normal conditions) of gas (gases) produced in the reaction between 10 g of sulfur and 100 g of concentrated (98 %) sulfuric acid.**

   _____

   _____

   _____

5. **Calculate the mass of $Na_2SO_3 \cdot 7H_2O$ which is needed to produce 5 L of SO_2 in normal conditions.**

_____

_____

_____

6. **Find the mass percentage of copper in its mixture with zinc. 20 g of that mixture reacted with the excess of dilute sulfuric acid and produced 1.1 L of a gas.**

_____

_____

_____

7. **The mixture of sulfur and phosphorus had a mass of 6 g. That mixture has been burnt completely in 4.4 L of oxygen. Find the mass percentage of sulfur in the initial mixture.**

_____

_____

_____

8. **The mass percentage of sulfur (VI) oxide in oleum is 20 %. What mass of that oleum is required to prepare 1 kg of pure sulfuric acid?**

_____

_____

_____

9. **The mass of the mixture made from copper and silver is 4 g. That mixture reacted with concentrated sulfuric acid and produced 0.9074 L of sulfur dioxide. Find the mass percentage of silver in the initial mixture.**

_____

_____

_____

10. **There are 5 g of sodium hydroxide in the water solution. 10 g of hydrogen sulfide have been dissolved in that solution. Determine what kind of salt(s) is formed and find out its (their) mass.**

_____

_____

_____

11. **What is the volume of hydrogen sulfide (in normal conditions) produced in the reaction between 13 g of zinc and 500 g of 10 % sulfuric acid solution?**

_____

_____

_____

12. **Calculate the molar concentration of sulfate anions in 200 ml of the water solution containing sodium sulfate and potassium sulfate. 10 g of barium chloride has been added to this solution. Precipitate has been separated. Then the excess of silver nitrate has been added to the remaining solution. The mass of precipitate was equal to 2 g.**

_____

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $H_2SO_4 \rightarrow H_2S \rightarrow KHS \rightarrow K_2S \rightarrow SO_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the second reaction in the complete and short ionic forms:

   _____

   _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $Li_2S \rightarrow H_2S \rightarrow S \rightarrow ZnS \rightarrow S$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the first reaction in the complete and short ionic forms:

   _____

   _____

   Write electron balance for the fourth reaction:

   _____

   _____

3. **What is the mass of sulfur in 20 kg of:**
   H_2SO_3 _____
   H_2SO_4 _____
   H_2S _____

4. **Calculate the volume (in normal conditions) of gas (gases) produced in the reaction between 10 g of sulfur and 100 g of concentrated (60 %) nitric acid.**

   _____
   _____
   _____
   _____

5. **There is a concentrated sulfuric acid solution (volume = 1 L; mass percentage = 96 %; density = 1.84 g/ml). Determine the volume of that solution that is needed to make 1 L of 1M H_2SO_4.**

   _____
   _____
   _____
   _____

6. **25 g of zinc reacted with concentrated sulfuric acid water solution that contains 70 g of sulfuric acid. Calculate the volume of sulfur (IV) oxide released in this process.**

   _____
   _____
   _____
   _____

7. **The mixture of zinc and aluminum had a mass of 15 g. That mixture reacted with dilute sulfuric acid and produced 68 g of salts. Find the mass percentage of zinc in the initial mixture.**

   _____
   _____
   _____
   _____

8. **The mass percentage of sulfur (VI) oxide in oleum is 10 %. What mass of that oleum is required to prepare 1 kg of sulfuric acid with the mass percentage of 30 %?**

   _____
   _____
   _____
   _____

9. **The mass of the mixture made from potassium and sodium sulfides is 5 g. That mixture reacted with hydrochloric acid and produced 1.2688 L of hydrogen sulfide. Find the mass percentage of potassium sulfide in the initial mixture.**

_____

_____

_____

_____

_____

10. **There are 7 g of sodium hydroxide in the water solution. 3 L of sulfur dioxide have been dissolved in that solution. Determine what kind of salt(s) is formed and find out its (their) mass.**

_____

_____

_____

_____

11. **What is the mass of sulfur produced in the reaction between 24 g of zinc and 500 g of 30 % sulfuric acid solution?**

_____

_____

_____

_____

12. **Calculate the mass percentage of sulfate anions in 300 g of the water solution containing lithium sulfate and cesium sulfate. 8 g of barium chloride has been added to this solution. Precipitate has been separated. Then the excess of silver nitrate has been added to the remaining solution. The mass of precipitate was equal to 1.5 g.**

_____

_____

_____

_____

_____

LESSON 5
NITROGEN AND ITS COMPOUNDS

5.1 NITROGEN AND AMMONIA

Elemental nitrogen (N_2) is a colorless, odorless, tasteless, and mostly inert diatomic gas at normal conditions, constituting 78 % of the atmosphere by volume.

There are several reactions in which molecular nitrogen can be produced in laboratory.

$NH_4NO_2 \rightarrow 2H_2O + N_2\uparrow$

$(NH_4)_2Cr_2O_7 \rightarrow Cr_2O_3 + 4H_2O + N_2\uparrow$

$3CuO + 2NH_3 \rightarrow 3Cu + N_2\uparrow + 3H_2O$

$5Mg + 12HNO_3 \rightarrow 5Mg(NO_3)_2 + N_2\uparrow + 6H_2O$

$NH_4Cl + NaNO_2 \rightarrow N_2\uparrow + NaCl + 2H_2O$

Lithium is the only one known substance which reacts with nitrogen gas in normal conditions. Nitrides of other metals are formed at higher temperatures.

$6Li + N_2 \rightarrow 2Li_3N$

$2Al + N_2 \rightarrow 2AlN$

Nitrides of metals react with water and produce ammonia.

$Mg_3N_2 + 6H_2O \rightarrow 3Mg(OH)_2\downarrow + 2NH_3\uparrow$

Nitrides react with acids and produce ammonium salts.

$Ca_3N_2 + 8HCl \rightarrow 3CaCl_2 + 2NH_4Cl$

Ammonia behaves as a weak base in water solutions.

$NH_3 + H_2O \rightleftarrows NH_4OH \rightleftarrows NH_4^+ + OH^-$

However, equilibriums of both processes described above are shifted towards reactants (ammonia and water). For this reason, water solution of ammonia may be described as $NH_3 \cdot H_2O$.

Ammonium cation (NH_4^+) is formed due to donor-acceptor (dative) bond formation between hydrogen cation (acceptor of the electron pair) and nitrogen from ammonia (donor of the electron pair). As a result, all the bonds in the NH_4^+ cation have the same length (figure 7).

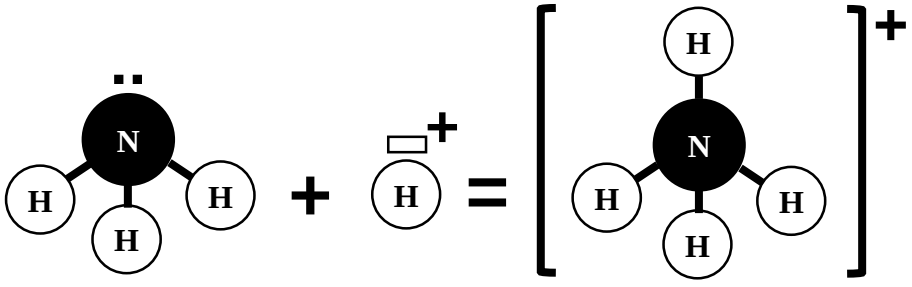


Figure 7. Ammonium cation formation

Ammonium hydroxide (NH_4OH) demonstrates all the properties of a weak base. In the mixture of ammonium salt and alkali newly produced NH_4OH decomposes into ammonia and water.

$NH_4NO_3 + NaOH \rightarrow NaNO_3 + H_2O + NH_3\uparrow$

Ammonia can react with oxygen at high temperature only.

$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$

In the presence of a catalyst the products of that reaction are different.

$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

Ammonium nitrate decomposes at high temperature into water and nitrogen (I) oxide.

$NH_4NO_3 \rightarrow 2H_2O + N_2O\uparrow$

At higher temperatures nitrogen (I) oxide decomposes as well.

$2NH_4NO_3 \rightarrow 4H_2O + 2N_2\uparrow + O_2\uparrow$

Nitrogen (III) oxide forms weak nitrous acid in the reaction with water.

$N_2O_3 + H_2O \rightarrow 2HNO_2$

Nitrogen (IV) oxide forms nitric acid in the reaction with water in the presence of oxygen.

$4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$

In the absence of oxygen both nitrous and nitric acids are produced in the reaction between NO_2 and H_2O.

$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$

Nitrogen (V) oxide forms just nitric acid in the reaction with water.

$N_2O_5 + H_2O \rightarrow 2HNO_3$

Nitrogen (IV) oxide can produce ammonia in the reaction with hydrogen gas.

$2NO_2 + 7H_2 \rightarrow 2NH_3 + 4H_2O$

5.2 PROPERTIES OF NITRIC ACID

Nitric acid (figure 8) demonstrates all the properties of strong acids: it reacts with bases, basic oxides and certain salts. Exceptional behavior of nitric acid is associated with the ability of its nitrogen atom to oxidize metals. However, cold concentrated nitric acid cannot react with such metals as iron, chrome and aluminum.

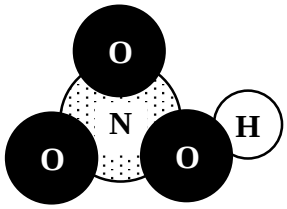


Figure 8. Structure of nitric acid molecule

It is important to remember that nitric acid never produces pure hydrogen gas in reactions with metals. There is always a mixture of products. Even so hydrogen may be produced in reaction between dilute nitric acid and certain metals, it immediately reacts with

other products of the reaction and forms water. As in case with sulfuric acid, concentration of nitric acid determines the main product in the reaction with metal. The lower its concentration, the lower the oxidation state of nitrogen atoms in the main product of that reaction.

$Mg + 4HNO_3 (\geq 60\ \%) \rightarrow Mg(NO_3)_2 + 2NO_2\uparrow + 2H_2O$

$3Mg + 8HNO_3 (30\ \%) \rightarrow 3Mg(NO_3)_2 + 2NO\uparrow + 4H_2O$

$3Mg + 10HNO_3 (20\ \%) \rightarrow 3Mg(NO_3)_2 + 2N_2O\uparrow + 5H_2O$

$5Mg + 12HNO_3 (10\ \%) \rightarrow 5Mg(NO_3)_2 + N_2\uparrow + 6H_2O$

$4Mg + 10HNO_3 (3\ \%) \rightarrow 4Mg(NO_3)_2 + NH_4NO_3 + 3H_2O$

Concentrated nitric acid is also able to oxidize some nonmetals.

$6HNO_3(concentrated) + S \rightarrow H_2SO_4 + 6NO_2\uparrow + 2H_2O$

$5HNO_3(concentrated) + P \rightarrow H_3PO_4 + 5NO_2\uparrow + H_2O$

$4HNO_3(concentrated) + C \rightarrow CO_2\uparrow + 4NO_2\uparrow + 2H_2O$

Nitrates (salts of nitric acid) of alkali (except lithium) and alkaline-earth metals can be decomposed into nitrites (salts of nitrous acid) and oxygen gas.

$2NaNO_3 \rightarrow 2NaNO_2 + O_2\uparrow$

Nitrates of metals situated between magnesium and copper in the reactivity series (including those two metals) decompose into corresponding metal oxides, nitric (IV) oxide and oxygen.

$4Al(NO_3)_3 \rightarrow 2Al_2O_3 + 12NO_2\uparrow + 3O_2\uparrow$

Nitrates of metals situated after the copper in the reactivity series produce pure metals, nitric (IV) oxide and oxygen in the decomposition reaction.

$2AgNO_3 \rightarrow 2Ag + 2NO_2 + O_2\uparrow$

Industrial method of nitric acid production includes three steps:

1. $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$
2. $2NO + O_2 \rightarrow 2NO_2$
3. $4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$

EXERCISES FOR CLASSWORK

1. Write four reactions according to the following classic chain of chemical reactions and balance them:

$N_2 \rightarrow NH_3 \rightarrow NH_4NO_3 \rightarrow N_2O \rightarrow NO_2$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write the kinetic equation for the fourth reaction, and the equation for the constant of equilibrium for that process:

_____

_____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $Cu(NO_3)_2 \rightarrow NO_2 \rightarrow HNO_3 \rightarrow KNO_3 \rightarrow KNO_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write electron balance for the second reaction:

   _____

   _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

3. **Calculate the volume of nitrogen (in normal conditions) which can be produced from 100 g of:**

   ammonium nitrite _____

   _____

   ammonium dichromate_____

   _____

4. **What is the volume (in normal conditions) of ammonia released from 200 g of 5 % (by mass) water solution of ammonium nitrate after the addition of 2 g of 10 % (by mass) water solution of sodium hydroxide?**

   _____

   _____

   _____

5. **Calculate the mass of nitric acid produced from 12 L of nitrogen (IV) oxide (in normal conditions) and 25 g of water in the presence of oxygen.**

   _____

   _____

   _____

6. **What is the mass of ammonium bromide formed in the reaction between 4 L of ammonia (in normal conditions) and 2 g of hydrogen bromide?**

   _____

   _____

   _____

7. **What is the mass of sodium nitrate formed in the reaction between 100 g of 5 % sodium hydroxide solution and 200 g of 10 % nitric acid?**

_____

_____

_____

_____

8. **Find the mass percentage of potassium nitrate in its mixture with iron (III) nitrate. 15 g of that mixture has been heated up and produced 2 L of a brown gas.**

_____

_____

_____

_____

9. **A mixture of copper and copper (II) oxide had a mass of 50 g. In the reaction between that mixture and concentrated nitric acid 2.3 L of a gas (in normal conditions) have been produced. What is the mass percentage of copper (II) oxide in the mixture?**

_____

_____

_____

_____

10. **Determine the yield (in %) of the copper nitrate thermal decomposition, if the decrease of the mass of the portion of that salt was equal to 15 %.**

_____

_____

_____

11. **Determine the yield (in %) of the sodium nitrate thermal decomposition, if the increase of the mass percentage of nitrogen atoms in the solid sample was equal to 2 %.**

_____

_____

_____

12. **The average molar mass of gases produced in the reaction between aluminum and limited amount of nitric acid is equal to 23 g/mol. These gases do not contain oxygen atoms. Find the mass of aluminum reacted with 10 g of nitric acid.**

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $HNO_2 \rightarrow HNO_3 \rightarrow Zn(NO_3)_2 \rightarrow NO_2 \rightarrow NaNO_3$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the second reaction in the complete and short ionic forms:

   _____

   _____

   Write electron balance for the second reaction:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $Zn(NO_3)_2 \rightarrow Ba(NO_3)_2 \rightarrow HNO_3 \rightarrow AgNO_3 \rightarrow KNO_3$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the first reaction in the complete and short ionic forms:

   _____

   _____

   Write the second reaction in the complete and short ionic forms:

   _____

   _____

3. **Calculate the volume of oxygen gas (in normal conditions) which is required to burn down 20 L of ammonia:**

   with a catalyst _____

   _____

   without a catalyst_____

   _____

4. **What is the volume (in normal conditions) of ammonia released from 150 g of 3 % (by mass) water solution of ammonium sulfate after the addition of 6 g of 20 % (by mass) water solution of potassium hydroxide?**

_____

_____

_____

5. **Calculate the mass of nitric acid produced from 10 L of nitrogen (IV) oxide (in normal conditions) and 7 g of water in the absence of oxygen.**

_____

_____

_____

6. **What is the volume of nitrogen (in normal conditions) formed after the decomposition of 6 g of ammonium nitrite?**

_____

_____

_____

7. **Calculate the volume of nitrogen released in the reaction between 18 g of nitric acid and 3 g of zinc.**

_____

_____

_____

_____

8. **Find the mass percentage of copper (II) nitrate decomposed during the heating. The initial mass was equal to 20 g. The final mass of the mixture of solid substances after the heating is equal to 18 g.**

_____

_____

_____

_____

9. **15 g of a mixture of silver and copper (II) nitrates has been heated up. As a result, 0.96 L of oxygen (in normal conditions) have been produced. Determine the mass percentage of silver nitrate in that mixture.**

_____

_____

_____

_____

10. **Determine the yield (in %) of the silver nitrate thermal decomposition, if the decrease of the mass of the portion of that salt was equal to 10 %.**

_____

_____

_____

_____

11. **Determine the yield (in %) of the potassium nitrate thermal decomposition, if the increase of the mass percentage of nitrogen atoms in the solid sample was equal to 2.5 %.**

_____

_____

_____

_____

12. **The average molar mass of gases produced in the reaction between zinc and limited amount of nitric acid is equal to 25 g/mol. These gases do not contain oxygen atoms. Find the mass of zinc reacted with 20 g of nitric acid.**

_____

_____

_____

_____

LESSON 6
PHOSPHORUS AND ITS COMPOUNDS

6.1 PHOSPHORUS

Phosphorus exists as several forms that exhibit strikingly different properties. The two most common allotropes are white phosphorus and red phosphorus. Black phosphorus is obtained by heating white phosphorus under high pressure. White phosphorus is a molecular substance with P_4 molecule (figure 9). Red phosphorus is amorphous, while black phosphorus has an atomic crystal structure. The most reactive allotropic modification of phosphorus is white phosphorus, the most stable one is black phosphorus.

Industrial method to produce phosphorus is to heat up the mixture of calcium phosphate with sand and coal.

$Ca_3(PO_4)_2 + 5C + 3SiO_2 \rightarrow 3CaSiO_3 + 2P + 5CO$

Phosphorus can react with concentrated nitric and sulfuric acids. Phosphoric acid is one of the products of those reactions.

$5HNO_3(\text{concentrated}) + P \rightarrow H_3PO_4 + 5NO_2\uparrow + H_2O$

$2P + 5H_2SO_4(\text{concentrated}) \rightarrow 2H_3PO_4 + 5SO_2\uparrow + 2H_2O$

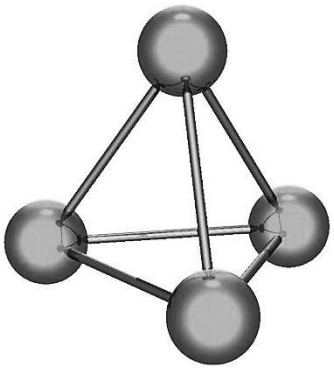


Figure 9. Structure of white phosphorus molecule (P_4)

6.2 PHOSPHORUS CONTAINING COMPOUNDS

Phosphorus reacts with metals and produces phosphides of metals.

$Al + P \rightarrow AlP$

Those phosphides of metals can react with water and acids to produce phosphine.

$Mg_3P_2 + 6H_2O \rightarrow 3Mg(OH)_2\downarrow + 2PH_3\uparrow$

$Ca_3P_2 + 6HCl \rightarrow 3CaCl_2 + 2PH_3\uparrow$

Immediate phosphine combustion results in phosphorus (V) oxide formation.

$2PH_3 + 4O_2 \rightarrow P_2O_5 + 3H_2O$

Phosphorus (III) oxide forms phosphorous acid in the reaction with water.

$P_2O_3 + 3H_2O \rightarrow 2H_3PO_3$

Phosphorus (III) oxide can be easily oxidized and form phosphorus (V) oxide.

$P_2O_3 + O_2 \rightarrow P_2O_5$

Phosphorus (V) oxide forms phosphoric acid in the reaction with water at high temperature.

$P_2O_5 + 3H_2O \rightarrow 2H_3PO_4$

Phosphoric acid demonstrates all the properties of weak acids. It is important to highlight that there are two types of acidic salts (dihydrogen phosphates and hydrogen phosphates) which can be produced from phosphoric acid (figure 10). The nature of the product of the phosphoric acid neutralization reaction depends on the molar ratio between the acid and the base.

$NaOH + H_3PO_4 \rightarrow NaH_2PO_4 + H_2O$

$2NaOH + H_3PO_4 \rightarrow Na_2HPO_4 + 2H_2O$

$3NaOH + H_3PO_4 \rightarrow Na_3PO_4 + 3H_2O$

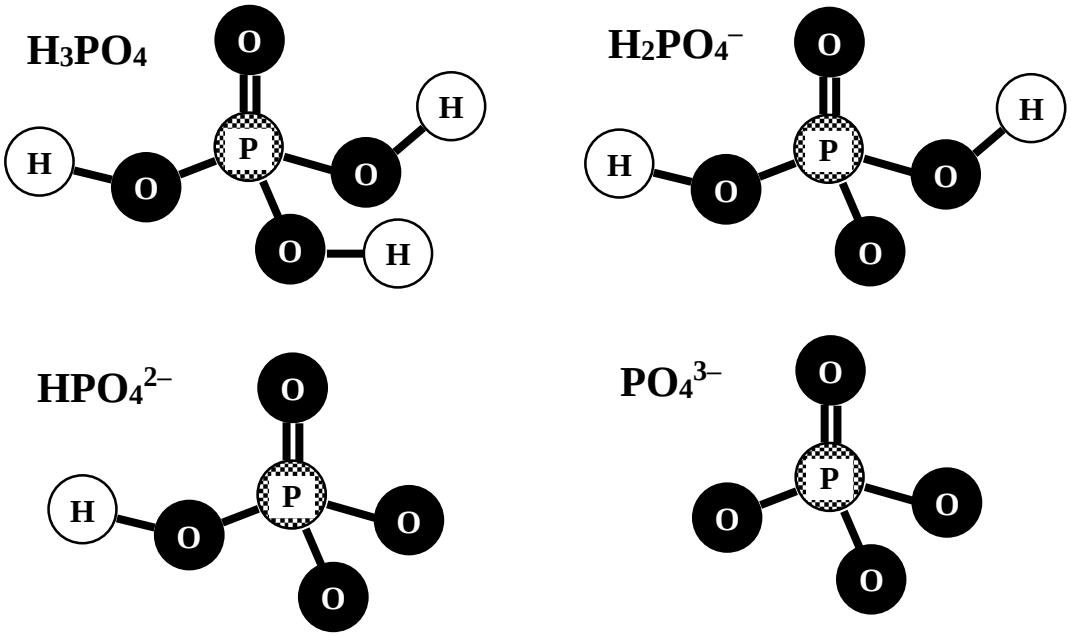


Figure 10. Structures of phosphoric acid and its anions

TEST FOR CLASSWORK

1. Choose formulas of compounds in which nitrogen has negative oxidation state:
   a) Na_3N b) NaN_3 c) NH_4Br d) NO_2
2. During NH_4^+ cation formation nitrogen atom behaves as:
   a) electron pair donor
   b) electron pair acceptor
   c) proton donor
   d) proton acceptor
3. Choose redox reactions:
   a) $N_2O_3 + H_2O \rightarrow$ c) $N_2O_5 + H_2O \rightarrow$
   b) $NO_2 + H_2O \rightarrow$ d) $NH_3 + O_2 \rightarrow$

4. NO_2 will be released in reactions:
   a) KNO_3 (t°) →
   b) $Zn(NO_3)_2$ (t°) →
   c) $AgNO_3$ (t°) →
   d) $Cu + HNO_{3\ (concentrated)}$ →
5. Which substances react with HNO_3:
   a) Hg b) KOH c) KCl d) Au
6. Choose molecular compounds:
   a) white phosphorus
   b) red phosphorus
   c) ammonia
   d) ammonium chloride
7. Gas will be released in the reaction:
   a) $Fe + HNO_3$ →
   b) $NH_4Cl + K_3PO_4$ →
   c) $FeO + HNO_3$ →
   d) NH_4NO_3 (t°) →
8. Calculate the sum of all coefficients in the redox reaction:
   $Zn + HNO_3 \rightarrow Zn(NO_3)_2 + N_2O + H_2O$
   a) 10 b) 13 c) 24 d) 20
9. Which reactions can be expressed by the following ionic equation:
   $3Ca^{2+} + 2PO_4^{3-} \rightarrow Ca_3(PO_4)_2$
   a) $3CaCl_2 + 2H_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6HCl$
   b) $3CaCl_2 + 2Na_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6NaCl$
   c) $3CaSO_4 + 2K_3PO_4 \rightarrow Ca_3(PO_4)_2 + 3K_2SO_4$
   d) $3Ca + 2H_3PO_4 \rightarrow Ca_3(PO_4)_2 + 3H_2$
10. Dihydrogen phosphate will be produced in the reaction between:
    a) 2 mol NaOH and 1 mol H_3PO_4
    b) 1 mol NaOH and 1 mol H_3PO_4
    c) 3 mol NaOH and 1 mol H_3PO_4
    d) 1 mol NaOH and 3 mol H_3PO_4

TEST FOR HOMEWORK

1. Choose formulas of compounds in which nitrogen has positive oxidation state:
   a) $NaNO_3$ b) $NaNO_2$ c) NH_3 d) N_2
2. Describe pH level in the water solution of ammonia?
   a) slightly acidic c) strongly acidic
   b) slightly basic d) strongly basic

3. Choose redox reactions:
   a) $NH_3 + HCl \rightarrow$
   b) $N_2 + H_2 \rightarrow$
   c) $NO + O_2 \rightarrow$
   d) $AgNO_3 + KCl \rightarrow$

4. O_2 will be released in reactions:
   a) $NaNO_3$ (t°) →
   b) $Cu(NO_3)_2$ (t°) →
   c) NH_4NO_3 (t°) →
   d) NH_4NO_2 (t°) →

5. Which substances react with $AgNO_3$:
   a) KF b) KCl c) KBr d) KI

6. Choose ionic compounds:
   a) phosphine
   b) phosphorus (III) chloride
   c) ammonium phosphate
   d) potassium dihydrogen phosphate

7. Water will be produced in the reaction:
   a) $Zn + HNO_3 \rightarrow$
   b) $NH_4Cl + H_3PO_4 \rightarrow$
   c) $CuO + HNO_3 \rightarrow$
   d) $NH_4Cl + KOH \rightarrow$

8. Calculate the sum of all coefficients in the redox reaction:
   $Ca + HNO_3 \rightarrow Ca(NO_3)_2 + N_2 + H_2O$
   a) 12 b) 17 c) 27 d) 29

9. Which reactions can be expressed by the ionic equation: $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$
   a) $NH_4NO_3 + LiOH \rightarrow LiNO_3 + NH_3 + H_2O$
   b) $(NH_4)_2SO_4 + Ba(OH)_2 \rightarrow BaSO_4 + 2NH_3 + 2H_2O$
   c) $NH_4Cl + NaOH \rightarrow NaCl + NH_3 + H_2O$
   d) $NH_4H_2PO_4 + 3KOH \rightarrow K_3PO_4 + NH_3 + 3H_2O$

10. Monohydrogen phosphate will be produced in the reaction between:
    a) 2 mol NaOH and 1 mol H_3PO_4
    b) 1 mol NaOH and 2 mol H_3PO_4
    c) 4 mol NaOH and 1 mol H_3PO_4
    d) 1 mol NaOH and 3 mol H_3PO_4

EXERCISES FOR CLASSWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $P \rightarrow P_2O_3 \rightarrow P_2O_5 \rightarrow H_3PO_4 \rightarrow Ca_3(PO_4)_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $H_3PO_4 \rightarrow K_3PO_4 \rightarrow K_2HPO_4 \rightarrow KH_2PO_4 \rightarrow Na_3PO_4$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the second reaction in the complete and short ionic forms:

   _____

   _____

3. **Calculate the mass percentage of phosphorus oxide (V) in:**

   calcium dihydrogen phosphate ($Ca(H_2PO_4)_2$)

   _____

   calcium hydrogen phosphate ($CaHPO_4$)

   _____

   calcium phosphate ($Ca_3(PO_4)_2$)

   _____

4. **How much phosphorus (g) can be produced from 1 kg of calcium phosphate?**

   _____

   _____

5. **Calculate the mass of phosphorus (V) oxide that is needed to make 300 ml of (ortho)phosphoric acid solution with the molarity of 0.1 mol/L.**

   _____

   _____

   _____

6. **Calculate the mass of a product of the reaction between 3 g of calcium oxide and 9 g of phosphorus (V) oxide.**

_____

_____

_____

7. **Calculate the mass of a salt(s) produced in the reaction between 5 g of barium oxide and 8 g of phosphoric acid.**

_____

_____

_____

_____

8. **The mass of phosphorus is equal to 2.5 g, the mass of sulfur is equal to 5 g. That mixture reacted with concentrated sulfuric acid. Calculate the volume of a gas (gases) produced in these processes (in normal conditions).**

_____

_____

_____

_____

9. **What salt will be formed in the reaction between 17 g of sodium hydroxide and 190 g of phosphoric acid? Calculate the mass of a salt(s).**

_____

_____

_____

_____

10. **Calculate the mass of phosphorus (V) oxide produced from phosphine oxidation. Phosphine has been released during hydrolysis of 450 g of magnesium phosphide.**

_____

_____

_____

_____

11. **3.1 g of phosphorus have been burnt. Phosphorus (V) oxide has been produced. That phosphorus (V) oxide has been dissolved in 70 ml of 14 % potassium hydroxide solution with density equal to 1.14 g/ml. Calculate the mass percentage of a salt(s) in the final solution.**

_____

_____

_____

_____

12. **Calcium phosphate reacted with concentrated sulfuric acid. As a result, the mass percentage of phosphorus in the mixture of phosphorus containing salts reached the level of 25 %. Calculate the mass percentages (%) of resulting salts containing phosphorus.**

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $H_3PO_4 \rightarrow Ca(H_2PO_4)_2 \rightarrow NaH_2PO_4 \rightarrow Na_3PO_4 \rightarrow Li_3PO_4$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $P \rightarrow P_2O_5 \rightarrow H_3PO_4 \rightarrow Na_3PO_4 \rightarrow Zn_3(PO_4)_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

3. **Calculate the mass percentage of phosphorus oxide (V) in:**

   ammonium dihydrogen phosphate ($NH_4H_2PO_4$)

   _____

   ammonium hydrogen phosphate ($(NH_4)_2HPO_4$)

   _____

   ammonium phosphate ($(NH_4)_3PO_4$)

   _____

4. **What is the mass of coal required to produce 2 kg of phosphorus in the reaction between calcium phosphate and silicon dioxide?**

_____

_____

_____

5. **Calculate the mass of phosphorus that is needed to make 200 ml of (ortho)phosphoric acid solution with the molarity of 0.05 mol/L.**

_____

_____

_____

_____

6. **Calculate the mass of a product of the reaction between 2 g of sodium oxide and 8 g of phosphorus (V) oxide.**

_____

_____

_____

_____

7. **Calculate the mass of a salt(s) produced in the reaction between 4 g of potassium hydroxide and 10 g of phosphoric acid.**

_____

_____

_____

_____

_____

8. **The mass of phosphorus is equal to 15 g, the mass of sulfur is equal to 8 g. That mixture reacted with concentrated nitric acid. Calculate the volume of a gas (gases) produced in these processes (in normal conditions).**

_____

_____

_____

_____

_____

9. **What salt will be formed in the reaction between 11 g of magnesium hydroxide and 3 g of phosphoric acid? Calculate the mass of a salt(s).**

_____

_____

_____

_____

10. **Calculate the mass of phosphorus (V) oxide produced from phosphine oxidation. Phosphine has been released during hydrolysis of 300 g of calcium phosphide.**

_____

_____

_____

_____

11. **13.3 g of phosphorus have been burnt. Phosphorus (V) oxide has been produced. That phosphorus (V) oxide has been dissolved in 80 ml of 5 % potassium hydroxide solution with density equal to 1.04 g/ml. Calculate the mass percentage of a salt(s) in the final solution.**

_____

_____

_____

_____

_____

12. **Calcium phosphate reacted with concentrated sulfuric acid. As a result, the mass percentage of calcium in the mixture of phosphorus containing salts decreased until the level of 20 %. Calculate the mass percentages (%) of resulting salts containing phosphorus.**

_____

_____

_____

_____

_____

LESSON 7
CARBON AND ITS COMPOUNDS

7.1 CARBON

There are several allotropes of carbon of which the best known are graphite, diamond, and amorphous carbon. Diamond is the hardest naturally-occurring material known, while graphite is soft enough to form a streak on paper (that is why it is used in pencils).

As it is shown in figure 11, electron orbitals of carbon atoms in diamond are in the sp^3 hybridization state. Each carbon atom makes four bonds to other atoms. All of those bonds are of the same length.

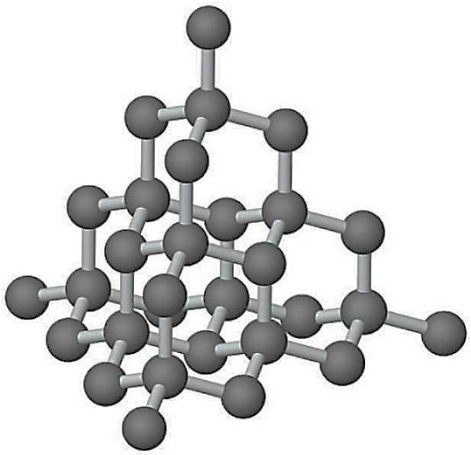


Figure 11. Structure of diamond

In graphite electron orbitals of carbon atoms are in the sp^2 hybridization state. Each carbon atom makes three bonds to other atoms. Each layer of graphite is the combination of numerous planar hexagons (figure 12). The bonds between those layers are much weaker than the bonds within layers. For this reason, layers can be easily separated from each other. Thanks to this phenomenon we are able to write with the help of pencil (its rod is usually made from graphite).

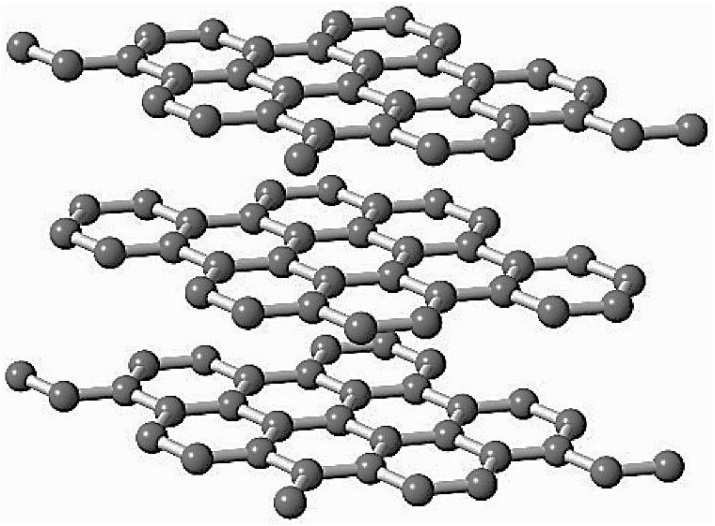


Figure 12. Structure of graphite

There are numerous artificial allotropic modifications of carbon. The most of them are based on carbon hexagons (graphite-like ones) arranged as football (soccer) balls, as tubes, spheres or ellipsoids. Their common name is fullerenes.

In carbyne (linear acetylenic carbon) there are alternating single and triple bonds $(-C\equiv C-C\equiv C-)_n$. So, electron orbitals in carbon atoms from carbyne are in sp^1 hybridization state.

Carbon is able to form very long chains of atoms connected by very strong and stable C–C, C=C or C≡C bonds. This property allows carbon to form an almost infinite number of compounds (there are more known carbon-containing compounds than all the compounds of the other chemical elements combined except those of hydrogen, because almost all organic compounds contain hydrogen too).

Carbon (in amorphous form of soot) reacts with an excess of oxygen and produces carbon dioxide.

$C + O_2 \rightarrow CO_2$

If there is a deficit of oxygen carbon dioxide can react with soot and form dangerous carbon monooxide which combines with hemoglobin to produce carboxyhemoglobin. Oxygen at the regular concentration is unable to replace CO in the carboxyhemoglobin, so the transport of oxygen to body tissues fails.

$CO_2 + C \rightarrow 2CO$

Carbon in form of soot is used in metallurgy with the aim to produce metals from their oxides. Both carbon monoxide and carbon dioxide can be produced in these reactions.

$Fe_2O_3 + 3C \rightarrow 2Fe + 3CO\uparrow$

$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2\uparrow$

$CuO + C \rightarrow Cu + CO\uparrow$

$2CuO + C \rightarrow 2Cu + CO_2\uparrow$

Soot also reacts with concentrated sulfuric and nitric acids.

$C + 2H_2SO_4(\text{concentrated}) \rightarrow CO_2\uparrow + 2SO_2\uparrow + 2H_2O$

$C + 4HNO_3(\text{concentrated}) \rightarrow CO_2\uparrow + 4NO_2\uparrow + 2H_2O$

7.2 Compounds of Carbon

Salt-like carbides are composed of highly electropositive elements and carbon. Those carbides can be further classified into methanides (with «C^{4-}» anion); acetylides (with two-atom anions «C_2^{2-}»; and sesquicarbides (with three-atom units «C_3^{4-}»).

Methanides, such as aluminum carbide, produce methane in the reaction with water.

$Al_4C_3 + 12H_2O \rightarrow 4Al(OH)_3\downarrow + 3CH_4\uparrow$

Acetylides produce acetylene in the reaction with water.

$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2\uparrow$

Sesquicarbides, such as Mg_2C_3, produce a variety of hydrocarbon products in the reaction with water.

Carbon dioxide (CO_2) demonstrates all the properties of acidic oxides. Carbonic acid (H_2CO_3) decomposes into CO_2 and H_2O in water solutions. That is why carbonates (salts of carbonic acid) produce CO_2 in reactions with acids.

$Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2\uparrow + H_2O$

All the carbonates (except carbonates of all alkali metals but not a lithium carbonate) can be decomposed into oxides of corresponding metals and CO_2.

$CaCO_3 \rightarrow CaO + CO_2\uparrow$

Acidic salts of carbonic acid (hydrogen carbonates — figure 13) and alkali-earth metals demonstrate better solubility in water than carbonates. Hydrogen-carbonates (usually called bicarbonates) decompose into carbonates, CO_2 and H_2O in the boiling water.

$Ca(HCO_3)_2 \rightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O$

$Mg(HCO_3)_2 \rightarrow MgCO_3\downarrow + CO_2\uparrow + H_2O$

So, some part of calcium and magnesium cations can be removed from water by the way of boiling.

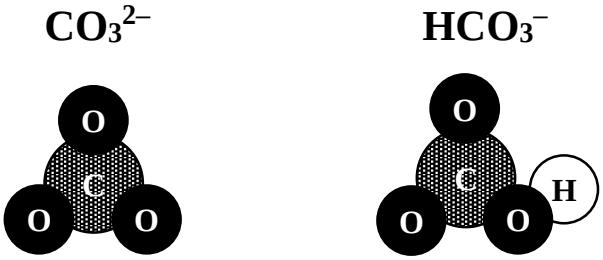


Figure 13. Structures of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) anions

EXERCISES FOR CLASSWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $C \rightarrow CO_2 \rightarrow Na_2CO_3 \rightarrow CaCO_3 \rightarrow CO_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $Al_4C_3 \rightarrow CH_4 \rightarrow CO_2 \rightarrow CO \rightarrow CO_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the kinetic equation for the second reaction, and the equation for the constant of equilibrium for that process:

   _____

   _____

   Write the kinetic equation for the third reaction, and the equation for the constant of equilibrium for that process:

   _____

   _____

3. **Calculate the mass of carbon in 10 L of carbon dioxide.**

   _____

   _____

4. **What is the volume of oxygen required to oxidize 2.6 L of carbon (II) oxide?**

   _____

   _____

5. **Calculate the volume of carbon (IV) oxide produced after the addition of the excess of hydrochloric acid to 100 ml of 0.2M solution of sodium carbonate.**

   _____

   _____

   _____

6. **Calculate the mass of a product of the reaction between 2 g of calcium oxide and 3 L of carbon dioxide.**

   _____

   _____

   _____

7. **The coal has been burned in the excess of oxygen. The gas formed during that reaction has been passed through the excess of lime water and produced 201.5 g of precipitate. Calculate the mass percentage of impurities in the coal if the initial mass of a sample was equal to 50 g.**

   _____

   _____

   _____

8. **Determine the mass of $CaCO_3$ produced after the boiling of water contained 0.001 M of $Ca(HCO_3)_2$. The volume of water is equal to 3 L.**

_____

_____

_____

9. **20 g of sodium bicarbonate have been decomposed and produced 2.24 L of CO_2 (in normal conditions). Determine the yield of that reaction.**

_____

_____

_____

10. **Calculate the mass of a salt(s) produced in the reaction between 5 L of carbon dioxide and 30 g of potassium hydroxide solution with the mass percentage of 5 %.**

_____

_____

_____

_____

11. **After the addition of 65 g of hydrochloric acid with the mass percentage of 20 % to 200 g of water solution containing sodium carbonate and potassium carbonate, the mass of the initial solution increased by 28.84 %. Calculate the mass percentage of carbonate ions in the initial solution.**

_____

_____

_____

12. **The mass of the mixture of calcium carbonate and barium carbonate is 500 g. The mass of the mixture after the complete thermal decomposition is 345 g. Find the mass percentage of calcium carbonate in the initial mixture.**

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $K_2CO_3 \rightarrow CO_2 \rightarrow CaCO_3 \rightarrow Ca(HCO_3)_2 \rightarrow Na_2CO_3$

   1. _____
   2. _____
   3. _____
   4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $CaC_2 \rightarrow C_2H_2 \rightarrow CO_2 \rightarrow (NH_4)_2CO_3 \rightarrow CO_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

3. **Calculate the mass of carbon in 20 L of carbon monoxide.**

   _____

   _____

4. **What is the mass of coal reacted with carbon dioxide and produced 2.5 L of carbon dioxide?**

   _____

   _____

5. **Calculate the volume of carbon (IV) oxide produced after the addition of the excess of sulfuric acid to 200 ml of 0.1M solution of potassium carbonate.**

   _____

   _____

   _____

6. **Calculate the mass of a product of the reaction between 3 g of strontium oxide and 5 L of carbon dioxide.**

   _____

   _____

   _____

7. **Calculate the mass of a salt(s) produced in the reaction between 6 L of carbon dioxide and 25 g of calcium hydroxide solution with the mass percentage of 3 %.**

_____

_____

_____

8. **Determine the mass of $MgCO_3$ produced after the boiling of water contained 0.0001 M of $Mg(HCO_3)_2$. The volume of water is equal to 2 L.**

_____

_____

_____

9. **10 g of potassium bicarbonate have been decomposed and produced 0.55 L of CO_2 (in normal conditions). Determine the yield of that reaction.**

_____

_____

_____

10. **50 g of hydrochloric acid with the mass percentage of 20% has been added to 300 g of water solution containing 5 g of sodium carbonate and 6 g of potassium carbonate. Find the increase in mass (%) of the initial solution.**

_____

_____

_____

_____

11. **The mass of the mixture of sodium carbonate and potassium carbonate is 10 g. The volume of a gas produced after the reaction with the excess of hydrochloric acid is equal to 1.8686 L. Find the mass percentage of sodium carbonate in the initial mixture.**

_____

_____

_____

_____

12. **What is the mass of iron produced from Fe_2O_3 in its reaction with soot if the density per hydrogen of the resulting mixture of carbon monoxide and carbon dioxide is equal to 19?**

_____

_____

_____

_____

LESSON 8
SILICON AND ITS COMPOUNDS

8.1 SILICON

Silicon is solid at room temperature. Elemental silicon has a large impact on the modern world economy. Although the portion of very highly purified silicon that is used in semiconductor electronics is relatively small (<10 %), a great deal of modern technology depends on it. Silicon is used in integrated circuits which are essential for microprocessors of computers.

Numerous minerals found in the Earth crust contain silicon, while for living organisms silicon is just a microelement.

Chains of hydrosilicons (compounds made from silicon and hydrogen atoms) can incorporate up to 60 silicon atoms. Even though silicon is able to form numerous compounds with hydrogen (including branched ones), those compounds are not as stable as hydrocarbons. To understand why carbon and not silicon forms all the compounds found in living organisms (DNA, RNA, proteins, carbohydrates, fats, etc.) one has to compare such features of carbon and silicon, as: atomic radii, electron configurations, existence of empty electron orbitals, electronegativity, polarity of bonds with hydrogen. Carbon has just 4 orbitals on its outer layer, and it has just 4 electrons. In hydrocarbons there are no lone pairs of electrons or empty orbitals. Silicon, as an element from 3rd period, already has d-orbitals that make its compounds much more reactive.

Silicon can be produced from SiO_2 in reactions with carbon or metals at high temperature.

$SiO_2 + 2C \rightarrow 2CO + Si$

$SiO_2 + 2Mg \rightarrow 2MgO + Si$

Metals can react with silicon and produce silicides. In these compounds the oxidation state of silicon is equal to – 4.

$2Mg + Si \rightarrow Mg_2Si$

$2Ca + Si \rightarrow Ca_2Si$

Silicon directly reacts with alkali and produces silicates and hydrogen gas.

$Si + 2NaOH + H_2O \rightarrow Na_2SiO_3 + 2H_2\uparrow$

8.2 COMPOUNDS OF SILICON

Dispersed silicon (IV) oxide is known as sand. Crystalline SiO_2 is known as quartz, while it forms more than a dozen of polymorphic modifications. It cannot react with water, even though it demonstrates acidic properties. For example, silicon dioxide can react with basic oxides at high temperature.

$SiO_2 + CaO \rightarrow CaSiO_3$

That oxide also can replace other (more vaporous) oxides in salts during the thermal fusion.

$Ca_3(PO_4)_2 + 3SiO_2 \rightarrow 3CaSiO_3 + P_2O_5\uparrow$

$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2\uparrow$

Silicides are able to react with acids. Silane (SiH_4) is produced in those reactions.

$Mg_2Si + 4HCl \rightarrow 2MgCl_2 + SiH_4\uparrow$

Silane is easily oxidized by the air.

$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$

Silane (unlike methane) is able to react with alkali.

$SiH_4 + 2NaOH + H_2O \rightarrow Na_2SiO_3 + 4H_2\uparrow$

Silicates are salts of silicic acid (H_2SiO_3). That acid is insoluble in water solutions.

$Na_2SiO_3 + H_2O + CO_2 \rightarrow Na_2CO_3 + H_2SiO_3\downarrow$

TEST FOR CLASSWORK

1. In which kind of hybridization electron orbitals of the outer shell of carbon atoms exist in diamond?
   a) sp b) sp^2 c) sp^3 d) no hybridization
2. In which kind of hybridization electron orbitals of the outer shell of carbon atoms exist in graphite?
   a) sp b) sp^2 c) sp^3 d) no hybridization
3. Which substances should we add to $CaCO_3$ precipitate in water solution to dissolve it?
   a) HCl b) KOH c) CO_2 d) HNO_3
4. What gas is produced in CaC_2 hydrolysis reaction?
   a) CO_2 b) O_2 c) C_2H_2 d) H_2
5. What gas is produced in Al_4C_3 hydrolysis reaction?
   a) H_2 b) CH_4 c) CO_2 d) H_2S
6. In which reactions precipitate is formed?
   a) $Ca(OH)_2 + HCl \rightarrow$
   b) $CaCl_2 + Na_2CO_3 \rightarrow$
   c) $Na_2SiO_3 + HCl \rightarrow$
   d) $KHCO_3 + HCl \rightarrow$
7. Which reactions are possible?
   a) $K_2SiO_{3(aq)} + CO_2 \rightarrow$
   b) $Mg_2Si + HCl \rightarrow$
   c) $K_2CO_{3(s)} + SiO_2 \rightarrow$
   d) $Na_2SiO_3 + K_2CO_3 \rightarrow$

8. Calculate the sum of all coefficients in the redox reaction:
   $SiH_4 + NaOH + H_2O \rightarrow Na_2SiO_3 + H_2$
   a) 9 b) 10 c) 11 d) 12

9. In which reactions a gas is formed:
   a) $CaCO_3 + HCl \rightarrow$
   b) $CaCO_3 + CO_2 + H_2O \rightarrow$
   c) $Ca(HCO_3)_2 + H_2SO_4 \rightarrow$
   d) $Ca(HCO_3)_2$ (t°) $\rightarrow$

10. In which reactions carbon atoms behave as oxidizers?
    a) $C + CuO \rightarrow Cu + CO$
    b) $C + 4HNO_{3\,(concentrated)} \rightarrow CO_2 + 4NO_2 + 2H_2O$
    c) $C_2H_2 + H_2 \rightarrow C_2H_4$
    d) $2C + Ca \rightarrow CaC_2$

TEST FOR CLASSWORK

1. What is the type of crystal structure for SiO_2 in normal conditions?
   a) molecular b) ionic c) atomic d) metallic

2. With which chemical element hydrogen atoms form the most stable compounds?
   a) B b) Si c) C d) P

3. Which substances should we add to $Ca(OH)_2$ water solution to cause precipitation?
   a) HNO_3 b) K_2CO_3 c) excess of CO_2 d) limited CO_2

4. Choose carbonates which cannot be decomposed at high temperature:
   a) Na_2CO_3 b) K_2CO_3 c) $CaCO_3$ d) $MgCO_3$

5. Choose formulas of bicarbonates:
   a) $NaHCO_3$ b) $KHCO_3$ c) $Ca(HCO_3)_2$ d) $(MgOH)_2CO_3$

6. In which reactions precipitate is formed?
   a) $Ca(HCO_3)_2 + HCl \rightarrow$
   b) $Ca(HCO_3)_2 + KOH \rightarrow$
   c) $KHSiO_3 + HCl \rightarrow$
   d) $KHSiO_3 + KOH \rightarrow$

7. Which reactions are possible?
   a) $SiO_2 + H_2O \rightarrow$
   b) $Si + NaOH + H_2O \rightarrow$
   c) $CaCO_3 + SiO_2 \rightarrow$
   d) $Na_2SO_4 + K_2CO_3 \rightarrow$

8. Calculate the sum of all coefficients in the redox reaction: $Ca_2Si + HCl \rightarrow CaCl_2 + SiH_4$
   a) 6 b) 7 c) 8 d) 9

9. In which reactions a gas is formed:
   a) $CaC_2 + HCl \rightarrow$
   b) $K_2SiO_3 + CO_2 \rightarrow$
   c) Li_2CO_3 (t°) $\rightarrow$
   d) $NaHCO_3$ (t°) $\rightarrow$

10. In which reactions carbon atoms behave as reducers?
    a) $2C + O_2 \rightarrow 2CO$
    b) $C + O_2 \rightarrow CO_2$
    c) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
    d) $3C + 4Al \rightarrow Al_4C_3$

EXERCISES FOR CLASSWORK

1. Write four reactions according to the following classic chain of chemical reactions and balance them:

$K_2SiO_3 \rightarrow H_2SiO_3 \rightarrow Na_2SiO_3 \rightarrow H_2SiO_3 \rightarrow SiO_2$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write the third reaction in the complete and short ionic forms:

_____

_____

2. Write four reactions according to the following classic chain of chemical reactions and balance them:

$SiH_4 \rightarrow SiO_2 \rightarrow Na_2SiO_3 \rightarrow H_2SiO_3 \rightarrow BaSiO_3$

1. _____
2. _____
3. _____
4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

3. **Calculate the volume of carbon (IV) oxide produced after the reaction between 20 g of sodium carbonate and the excess of silicon (IV) oxide at high temperature.**

_____

_____

_____

4. **Determine the volume of carbon dioxide (in normal conditions) produced in the reaction between 80 g of silicon dioxide and 260 g of calcium carbonate.**

_____

_____

_____

5. **Calculate the mass of a product of the reaction between 3 g of barium oxide and 6 g of silicon (IV) oxide.**

_____

_____

_____

6. **48.8 kg of sodium silicate has been produced in the reaction between sodium hydroxide and 25 kg of sand at high temperature. What is the mass percentage of SiO_2 in the sand?**

_____

_____

_____

_____

7. **Find the volume of carbon dioxide that is enough to produce 10 g of silicic acid from the water solution with potassium silicate.**

_____

_____

_____

_____

8. **Calculate the mass of a precipitate produced in the reaction between 4 g of sodium silicate and 50 g of hydrochloric acid solution with the mass percentage of 12 %.**

_____

_____

_____

_____

9. **The mass of the mixture of silicon (IV) oxide and solid potassium silicate was 15 g. The mixture has been put into the solution of hydrochloric acid. Find the mass percentage of silicon (IV) oxide in the initial mixture if the mass of a precipitate after the reaction was equal to 12.6 g.**

_____

_____

_____

_____

10. **3.96 L of silane (in normal conditions) reacted with 400 g of water solution containing the mixture of sodium and potassium hydroxides. The overall mass percentage of these hydroxides is equal to 4.25%. Calculate the mass of sodium hydroxide in the initial solution.**

_____

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $SiO_2 \rightarrow Si \rightarrow Na_2SiO_3 \rightarrow H_2SiO_3 \rightarrow SiO_2$

   1. _____
   2. _____
   3. _____
   4. _____

   Write electron balance for the second reaction:

   _____

   _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $Ca_2Si \rightarrow SiH_4 \rightarrow SiO_2 \rightarrow CaSiO_3 \rightarrow SiO_2$

   1. _____
   2. _____
   3. _____
   4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

3. **Calculate the volume of carbon (IV) oxide produced after the reaction between 30 g of calcium carbonate and the excess of silicon (IV) oxide at high temperature.**

_____

_____

_____

4. **Determine the volume of carbon dioxide (in normal conditions) produced in the reaction between 90 g of silicon dioxide and 190 g of calcium carbonate.**

_____

_____

_____

5. **Calculate the mass of a product of the reaction between 2 g of potassium oxide and 4 g of silicon (IV) oxide.**

_____

_____

_____

6. **150 L of carbon dioxide has been produced in the reaction between sodium hydroxide and 500 g of sand at high temperature. What is the mass percentage of SiO_2 in the sand?**

_____

_____

_____

7. **Find the mass of potassium silicate in its water solution that is enough to produce 20 g of silicic acid after the reaction with carbon dioxide.**

_____

_____

_____

8. **Calculate the mass of a precipitate produced in the reaction between 7 g of potassium silicate and 55 g of nitric acid solution with the mass percentage of 22 %.**

_____

_____

_____

9. **The mass of the mixture of silicon (IV) oxide and silicic acid was 40 g. The mixture has been heated until the constant mass of 36 g. Find the mass percentage of silicon (IV) oxide in the initial mixture.**

_____

_____

_____

_____

10. **3.96 L of silane (in normal conditions) reacted with 400 g of water solution containing the mixture of sodium and potassium hydroxides. The overall mass percentage of these hydroxides is equal to 4.25%. Calculate the mass of potassium silicate in the final solution.**

_____

_____

_____

_____

_____

LESSON 9
ALKALI METALS AND THEIR COMPOUNDS

9.1 ALKALI METALS

Alkali metals can be found in the first group of the Periodic table. Hydrogen, of course, is a single element from the first group which is not a metal. Alkali metals are soft enough to be cut with a knife. Alkali metals are highly reactive in normal conditions because they are prone to lose their single electron from the outer shell to form cations with the charge of +1.

Because of the ability of metals to lose their electrons, there are atoms and positively charged anions in their crystal lattices (figure 14). Atoms lose their electrons much more frequently than cations gain them. We may say that in the piece of metal valence electrons are common for all the positively charged metal ions. That is why all those valence electrons form a so-called «sea of electrons» or «electron gas».

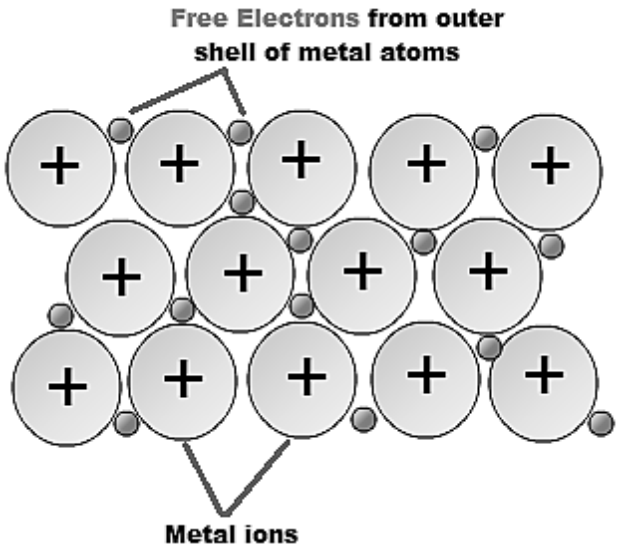


Figure 14. The scheme of metallic bonding

There are no negative ions in crystal lattices of metals. That fact is true for alloys as well. In the alloy made from two metals there are positive ions and atoms of both metals connected together by the common electron gas.

All the alkali metals react with water in normal conditions and produce alkali and hydrogen gas.

$2Li + 2H_2O \rightarrow 2LiOH + H_2\uparrow$

$2Na + 2H_2O \rightarrow 2NaOH + H_2\uparrow$

$2K + 2H_2O \rightarrow 2KOH + H_2\uparrow$

Reaction between sodium and water produces more heat than reaction between lithium and water. Because of this, sodium melts during that reaction. Reaction between potassium and water produces so much heat that it is enough to make releasing hydrogen gas burn.

Alkali metals react with hydrogen gas at high temperatures and produce hydrides.

$2Na + H_2 \rightarrow 2NaH$

Atomic radii of alkali metals increases if we move from the top to the bottom of the periodic table. However, the charge density (the ratio between the charge of a particle and the area of its surface) decreases for alkali metals' cations if we move from the top to the bottom of the periodic table. The higher the charge density of ion, the more water molecules make the solvate coat of that ion. So, radii of hydrated ions for these cations decrease if we move from the top to the bottom of the periodic table.

9.2 COMPOUNDS OF ALKALI METALS

Alkali can be produced from hydrides of alkali metals.

$LiH + H_2O \rightarrow LiOH + H_2\uparrow$

$3NaH + Fe_2O_3 \rightarrow 2Fe + 3NaOH$

$2KH + O_2 \rightarrow 2KOH$

Oxides (i. e. Na_2O), peroxides (i. e. Na_2O_2) and superoxides (NaO_2) can be produced in reaction between an alkali metal and oxygen. All those compounds are ionic: they contain metal cations and certain anions. In crystals of oxides there are O^{2-} anions, in crystals of peroxides there are O_2^{2-} anions (figure 15), while in crystals of superoxides there are O_2^- anions.

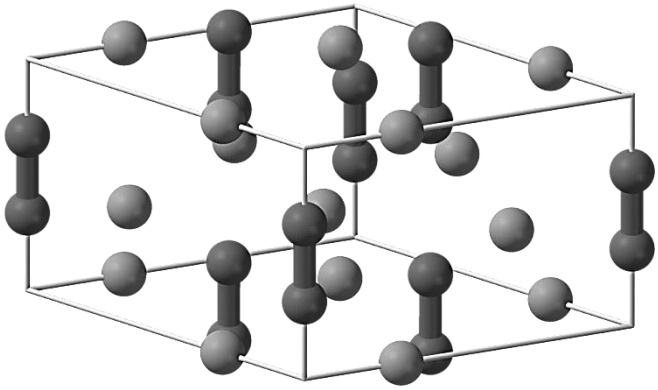


Figure 15. Structure of sodium peroxide. Sodium cations (Na^+) are grey, peroxide anions (O_2^{2-}) are dark

Peroxides of alkali metals are used in H_2O_2 production.

$Na_2O_2 + 2HCl \rightarrow 2NaCl + H_2O_2$

Oxides can be produced from peroxides and superoxides. An excess of pure metal is needed for that purpose.

$Na_2O_2 + 2Na \rightarrow 2Na_2O$

$KO_2 + 3K \rightarrow 2K_2O$

Oxides (and so hydroxides) of alkali metals demonstrate strong basic properties: they react with acids, acidic oxides and hydroxides.

$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$

$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$

$2LiOH + H_2SO_4 \rightarrow Li_2SO_4 + 2H_2O$

Hydroxides of alkali metals (except LiOH) cannot be decomposed into oxides and water (before the melting).

$2LiOH\ (temperature) \rightarrow Li_2O + H_2O$

$NaOH\ (temperature) \neq$

$KOH\ (temperature) \neq$

Nitrates of alkali metals are able to react with corresponding pure metals and produce oxides and nitrogen gas.

$10K + 2KNO_3 \rightarrow 6K_2O + N_2\uparrow$

EXERCISES FOR CLASSWORK

1. Write four reactions with *potassium* containing compounds according to the chain of chemical reactions

$K \xrightarrow{+S} A \xrightarrow{+HCl} B \xrightarrow{+AgNO_3} C \xrightarrow{t^\circ} D$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write the third reaction in the complete and short ionic forms:

_____

_____

2. Write four reactions with *sodium* containing compounds according to the chain of chemical reactions

$Na \xrightarrow{+H_2O} A \xrightarrow{+HI} B \xrightarrow{+Cl_2} C \xrightarrow{+AgNO_3} D$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write the third reaction in the complete and short ionic forms:

_____

_____

3. **Calculate the volume of hydrogen produced in the reaction between water and 50 g of:**

   lithium _____

   _____

   sodium _____

   _____

   potassium _____

   _____

4. **Calculate the mass of lithium in 5 g of lithium carbonate.**

   _____

   _____

   _____

5. **Determine the mass of 10% sodium hydroxide solution required for complete neutralization of 196 g of 20% sulfuric acid solution.**

   _____

   _____

   _____

6. **10 g of sodium has been dissolved in 400 g of water. Find the minimal mass of sulfuric acid solution with the mass percentage of 15 % needed to neutralize that sodium hydroxide solution.**

   _____

   _____

   _____

7. **Find the difference between mass percentages of potassium in its oxide and superoxide.**

   _____

   _____

   _____

   _____

8. **What kind of salt(s) is formed in the reaction between 8 g of potassium hydroxide and 9.8 g of phosphoric acid? Calculate the mass of that salt(s).**

   _____

   _____

   _____

   _____

9. **The alloy made from sodium and potassium has been dissolved in water. The volume of hydrogen released was equal to 3.77 L. Calculate the mass percentage of sodium in the alloy. The mass of the alloy was equal to 10 g.**

_____

_____

_____

_____

10. **Which substance can you add to the solution containing lithium and sodium hydroxides to remove lithium cations from it (in form of precipitate)? Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

11. **How can you confirm the presence of iodide ions in the solution of sodium iodide? Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions with ***lithium*** containing compounds according to the chain of chemical reactions**

   $Li \xrightarrow{+ O_2} A \xrightarrow{+ H_2O} B \xrightarrow{+ HCl} C \xrightarrow{+ AgNO_3} D$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions with ***potassium*** containing compounds according to the chain of chemical reactions**

   $1KOH \xrightarrow{+ H_3PO_4} A \xrightarrow{+ 1\,KOH} B \xrightarrow{+ 1KOH} C \xrightarrow{+ LiCl} D$

1. _____
2. _____
3. _____
4. _____

Write the first reaction in the complete and short ionic forms:

_____

_____

Write the second reaction in the complete and short ionic forms:

_____

_____

3. **Calculate the volume of hydrogen produced in the reaction between water and 50 g of:**

sodium hydride _____

_____

potassium hydride _____

_____

lithium hydride _____

_____

4. **Calculate the mass of cesium in 5 g of cesium chloride.**

_____

_____

_____

5. **Determine the mass of 8 % potassium hydroxide solution required for complete neutralization of 230 g of 10% hydrochloric acid.**

_____

_____

_____

6. **12 g of lithium has been dissolved in 300 g of water. Find the minimal mass of sulfuric acid solution with the mass percentage of 8 % needed to neutralize that lithium hydroxide solution.**

_____

_____

_____

_____

7. **Find the difference between mass percentages of sodium in its oxide and peroxide.**

_____

_____

_____

8. **What kind of salt(s) is formed in the reaction between 7 g of sodium hydroxide and 10.4 g of phosphoric acid? Calculate the mass of that salt(s).**

_____

_____

_____

_____

9. **The alloy made from lithium and potassium has been dissolved in water. The volume of hydrogen released was equal to 8.123 L. Calculate the mass percentage of lithium in the alloy. The mass of the alloy was equal to 10 g.**

_____

_____

_____

_____

10. **Which substance can you add to the solution containing sodium chloride and sodium fluoride to remove fluoride anions from it (in form of precipitate)? Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

11. **How can you confirm the presence of sulfate ions in the solution of sodium sulfate? Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

LESSON 10
ALKALINE-EARTH METALS AND THEIR COMPOUNDS

10.1 ALKALINE-EARTH METALS

Alkaline-earth metals occupy the second group of the Periodic table. However, alkali (soluble hydroxides) can be produced from Ca, Sr and Ba only, and not from Be and Mg. Moreover, Be demonstrates amphoteric features similar for those characteristic to Al.

For example, beryllium reacts with water solutions of alkali and forms complex salts.

$Be + 2NaOH + 2H_2O \rightarrow Na_2[Be(OH)_4] + H_2\uparrow$ (at high temperatures)

Magnesium reacts with water at high temperature and produces magnesium oxide.

$Mg + H_2O \rightarrow MgO + H_2\uparrow$

Very clean magnesium ribbon has a very slight reaction with cold water. After several minutes, some bubbles of hydrogen form on its surface. However, the reaction soon stops because the magnesium hydroxide formed is almost insoluble in water and becomes a barrier on the piece of magnesium preventing further reaction.

$Mg + 2H_2O \rightarrow Mg(OH)_2\downarrow + H_2\uparrow$

Just magnesium powder (in which the area of magnesium surface is very large) can react with water and produce magnesium hydroxide and hydrogen gas.

Calcium, strontium and barium react with water in a similar way as alkali metals.

$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2\uparrow$

$Sr + 2H_2O \rightarrow Sr(OH)_2 + H_2\uparrow$

$Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2\uparrow$

10.2 COMPOUNDS OF ALKALINE-EARTH METALS

Hydroxides of alkaline-earth metals can be decomposed into oxides and water at high temperature.

$Ca(OH)_2$ (temperature) $\rightarrow CaO + H_2O$

$Ba(OH)_2$ (temperature) $\rightarrow BaO + H_2O$

Sulfates of alkaline-earth metals decompose into oxides, sulfur (IV) oxide and oxygen.

$2SrSO_4 \rightarrow 2SrO + 2SO_2\uparrow + O_2\uparrow$

Oxides (and hydroxides) of Mg, Ca, Sr and Ba show basic properties: they react with acids and acidic oxides.

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3\downarrow + H_2O$

Water solution of calcium hydroxide (so-called «limewater») reacts with carbon dioxide. When the amount of carbon dioxide is lower than the amount of calcium hydroxide white precipitate of insoluble calcium carbonate begins to form. When the amount of carbon dioxide becomes higher $CaCO_3$ starts to react with it. As a result, white precipitate disappears because calcium bicarbonate is soluble, unlike calcium carbonate.

$CaCO_3\downarrow + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$

Common equation for limewater reaction with two times (or more) excess of carbon dioxide is written below.

$Ca(OH)_2 + 2CO_2 \rightarrow Ca(HCO_3)_2$

Hard water can be defined as a water with high concentration of calcium and magnesium cations. Water hardness can be divided into temporary hardness and permanent hardness. Temporary hardness is due to bicarbonate anions presence. That kind of hardness can be removed by the way of boiling.

$Ca(HCO_3)_2 \rightarrow CaCO_3\downarrow + 2CO_2\uparrow + H_2O$

$Mg(HCO_3)_2 \rightarrow MgCO_3\downarrow + 2CO_2\uparrow + H_2O$

Permanent hardness is due to the presence of anions other than bicarbonate. To fight the permanent hardness one needs to add some reactants (like washing soda — Na_2CO_3 or limewater — $Ca(OH)_2$) or use special filters which can catch Ca^{2+} and Mg^{2+} ions.

$Ca(HCO_3)_2 + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2NaHCO_3$

$Mg(HCO_3)_2 + Na_2CO_3 \rightarrow MgCO_3\downarrow + 2NaHCO_3$

$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3\downarrow + 2H_2O$

$Mg(HCO_3)_2 + Mg(OH)_2 \rightarrow 2MgCO_3\downarrow + 2H_2O$

EXERCISES FOR CLASSWORK

1. **Write four reactions with *calcium* containing compounds according to the chain of chemical reactions**

   $Ca \xrightarrow{+O_2} A \xrightarrow{+H_2O} B \xrightarrow{+1SO_2} C \xrightarrow{+2HCl} D$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions with *magnesium* containing compounds according to the chain of chemical reactions**

   $Mg \xrightarrow{+HCl\ (in\ excess)} A \xrightarrow{+KOH\ (in\ excess)} B \xrightarrow{t} C \xrightarrow{P_2O_5} D$

   1. _____
   2. _____
   3. _____
   4. _____

Write the first reaction in the complete and short ionic forms:

_____

_____

Write the second reaction in the complete and short ionic forms:

_____

_____

3. **Calculate the mass percentage (in %) of calcium in the:**
   calcite ($CaCO_3$) _____

   _____

   dolomite ($CaCO_3 \cdot MgCO_3$) _____

   _____

4. **What volume of hydrogen will be released after the mixing of 10 g of calcium and strontium alloy in water? Mass percentage of calcium in the alloy is 85 %.**

   _____

   _____

   _____

   _____

5. **Calculate the volume of carbon dioxide which will be enough to make the maximal amount of precipitate in 1 L of the solution of calcium hydroxide with the molarity equal to 0.05 mol/L.**

   _____

   _____

   _____

   _____

6. **Find the difference between mass percentages of calcium in its oxide and phosphate.**

   _____

   _____

   _____

   _____

7. **0.336 L of carbon dioxide have been dissolved in 300 ml of 0.01 M solution of calcium hydroxide. Determine the mass of a salt(s) produced in the reaction.**

   _____

   _____

   _____

   _____

8. **You have two tubes: one contains magnesium chloride, another contains strontium chloride. Which substance can you add to both of them to find out which one contains magnesium chloride. Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

9. **How can you confirm the presence of barium ions in the solution of barium chloride? Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

10. **The mass of barium sulfate produced in the reaction between barium chloride and 100 g of sodium sulfate water solution is equal to 1.2 g. Determine the mass percentage of sodium sulfate in the initial solution.**

_____

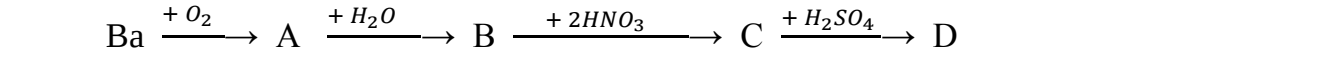
_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions with *barium* containing compounds according to the chain of chemical reactions**



1. _____
2. _____
3. _____
4. _____

Write the third reaction in the complete and short ionic forms:

_____

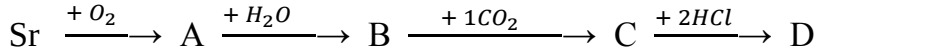
_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

2. **Write four reactions with ***strontium*** containing compounds according to the chain of chemical reactions**



1. _____
2. _____
3. _____
4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

3. **Calculate the mass percentage (in %) of calcium in:**
calcined gypsum powder ($CaSO_4 \cdot ½H_2O$) _____

_____

solid gypsum ($CaSO_4 \cdot 2H_2O$) _____

_____

4. **What volume of hydrogen will be released after the mixing of 5 g of barium and calcium alloy in water? Mass percentage of barium in the alloy is 20 %.**

_____

_____

_____

_____

5. **Calculate the mass of solid substances left after the heating of 200 g of magnesium hydroxide if the yield of the decomposition was 70 %.**

_____

_____

_____

_____

6. **Find the difference between mass percentages of barium in its oxide and peroxide.**

_____

_____

_____

_____

7. **2.15 L of carbon dioxide have been dissolved in 200 ml of 0.05 M solution of calcium hydroxide. Determine the mass of a salt(s) produced in the reaction.**

_____

_____

_____

_____

8. **You have two tubes: one contains potassium hydroxide, another contains barium hydroxide. Which substance can you add to both of them to find out which one contains barium hydroxide. Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

9. **How can you test the amphoteric properties of beryllium hydroxide? Write the reaction and its complete and short ionic forms:**

_____

_____

_____

_____

10. **The mass of barium sulfate produced in the reaction between 300 g of barium hydroxide water solution and 200 g of potassium sulfate water solution is equal to 3.3 g. Determine the mass percentage of potassium hydroxide in the final solution.**

_____

_____

_____

_____

LESSON 11
AMPHOTERIC METALS

11.1 ALUMINUM AND ITS COMPOUNDS

Aluminum is the third most abundant element (after oxygen and silicon), and the most abundant metal, in the Earth's crust. Aluminum is easily oxidized by oxygen.

$4Al + 3O_2 \rightarrow 2Al_2O_3$

Aluminum oxide (alumina) is responsible for the resistance of metallic aluminum to weathering. A thin passivation layer of aluminum oxide (~ 4 nm) forms on any exposed aluminum surface. This layer protects the metal from further oxidation. However, that passivation layer cannot protect aluminum from acids and bases.

$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$

$2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2\uparrow$

$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2Na[Al(OH)_4]$

$2Al + 2NaOH + 6H_2O \rightarrow 2Na[Al(OH)_4] + 3H_2\uparrow$

$2Al + 6NaOH + 6H_2O \rightarrow 2Na_3[Al(OH)_6] + 3H_2\uparrow$

Remember that aluminum is resistant to concentrated cold solutions of nitric and sulfuric acids, as well as to cold acetic and phosphoric acids.

Aluminum is able to reduce the most of metals from their oxides at high temperature.

$8Al + 3Fe_3O_4 \rightarrow 4Al_2O_3 + 9Fe$

Aluminum hydroxide is insoluble. That compound demonstrates amphoteric properties, as well as aluminum oxide.

$2Al(OH)_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2O$

When solid aluminum and sodium hydroxide are heated together, sodium aluminate ($NaAlO_2$) and water are formed.

$Al(OH)_3(solid) + NaOH(solid) \rightarrow NaAlO_2 + 2H_2O$

When aluminum hydroxide is added to the water solution of alkali, a complex salt will be formed. If the ratio between $Al(OH)_3$ and NaOH is equal to 1:1, resulting complex salt will be $Na[Al(OH)_4]$ — sodium tetrahydroxoaluminate.

$Al(OH)_3 + NaOH \rightarrow Na[Al(OH)_4]$

If the ratio between $Al(OH)_3$ and NaOH is 1 : 3 and higher (in the excess of concentrated alkali), the resulting complex salt will be $Na_3[Al(OH)_6]$ — sodium hexahydroxoaluminate.

$Al(OH)_3 + 3NaOH \rightarrow Na_3[Al(OH)_6]$

Complex salts (figure 16) are formed due to donor-acceptor bonds formation between empty electron orbitals of the central metal cation (Al^{3+} in our case) and electron pairs of ligands (oxygen atom from OH^- ions in our case).

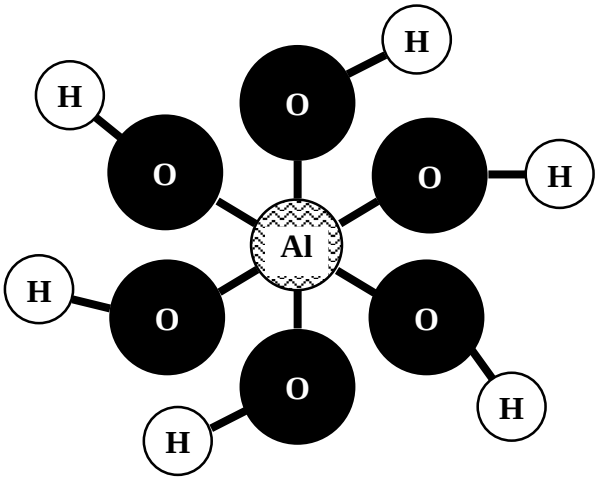


Figure 16. Scheme of hexahydroxoaluminate ($[Al(OH)_6]^{3-}$) anion

11.2 IRON AND ITS COMPOUNDS

Pure iron is soft (softer than aluminum), but it is unobtainable by smelting. The material is significantly hardened and strengthened by impurities from the smelting process, such as carbon.

Elemental iron occurs in meteoroids and other low oxygen environments, but it is reactive to oxygen and water. Fresh iron surfaces appear lustrous silvery-gray, but they are oxidized in normal air in the presence of water to give hydrated iron oxides (i. e. hydroxides), commonly known as rust ($Fe(OH)_3$). Unlike many other metals which form passivating oxide layers, iron oxides occupy more volume than iron metal, and thus iron oxides flake off and expose fresh surfaces for corrosion.

$4Fe + 6H_2O + 3O_2 \rightarrow 4Fe(OH)_3\downarrow$

At higher temperatures iron and water produce iron oxides $FeO \cdot Fe_2O_3$ ($=Fe_3O_4$). The higher the temperature, the higher the content of FeO in the final mixture.

$3Fe + 4H_2O$ (high temperature) $\rightarrow Fe_3O_4 + 4H_2\uparrow$

Iron forms iron (III) chloride in the reaction with chlorine gas.

$2Fe + 3Cl_2 \rightarrow 2FeCl_3$

In the reaction with hydrochloric acid, as well as with diluted sulfuric or nitric acid, salts of Fe^{2+} are formed.

$Fe + HCl \rightarrow FeCl_2 + H_2\uparrow$

$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2\uparrow$

Concentrated sulfuric and nitric acids oxidize Fe^0 to Fe^{3+}.

$2Fe + 6H_2SO_4(\text{concentrated}) \rightarrow Fe_2(SO_4)_3 + 3SO_2\uparrow + 6H_2O$

$Fe + 6HNO_3(\text{concentrated}) \rightarrow Fe(NO_3)_3 + 3NO_2\uparrow + 3H_2O$

Iron (II) hydroxide (mostly basic hydroxide) is quite instable substance which is easily oxidized by the air.

$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$

Iron (III) oxide and iron (III) hydroxide are amphoteric.

$Fe_2O_3 + 6HCl \rightarrow 2FeCl_3 + 3H_2O$

$Fe(OH)_3 + H_3PO_4 \rightarrow FePO_4 + 3H_2O$

If iron (III) oxide (or hydroxide) reacts with solid sodium hydroxide, sodium ferrite and water are formed at high temperature.

$Fe_2O_3(solid) + 2NaOH(solid) \rightarrow 2NaFeO_2 + H_2O$

$Fe(OH)_3(solid) + NaOH(solid) \rightarrow NaFeO_2 + 2H_2O$

If iron (III) oxide (or hydroxide) reacts with concentrated sodium hydroxide solution at high temperature, a complex salt (sodium hexahydroxoferrate) will be formed.

$Fe_2O_3 + 3H_2O + 6NaOH \rightarrow 2Na_3[Fe(OH)_6]$

$Fe(OH)_3 + 3NaOH \rightarrow Na_3[Fe(OH)_6]$

Concentrated alkali solutions are able to react with pure iron as well.

$2Fe + 2NaOH + 6H_2O \rightarrow 3H_2\uparrow + 2Na[Fe(OH)_4]\downarrow$

TEST FOR CLASSWORK

1. Choose metals which react with water at normal temperature and produce alkali:
   a) Li b) Na c) Zn d) Al
2. Choose hydroxides which can be decomposed at high temperature:
   a) $Ca(OH)_2$ b) KOH c) LiOH d) NaOH
3. Which cations are responsible of water hardness?
   a) Mg^{2+} b) Ca^{2+} c) Na^+ d) K^+
4. Choose compound that will be formed in the reaction between $AlCl_3$ and the excess of KOH water solution?
   a) $Al(OH)_3$
   b) $K[Al(OH)_4]$
   c) $K_3[Al(OH)_6]$
   d) $KAlO_2$
5. In which reactions iron is oxidized to Fe^{3+}?
   a) Fe + HCl
   b) $Fe + Cl_2$
   c) $Fe + H_2SO_4$ (dilute) $\rightarrow$
   d) $Fe + H_2O + O_2 \rightarrow$
6. Which reactions are possible?
   a) $CuCl_2 + Zn \rightarrow$
   b) $ZnCl_2 + Cu \rightarrow$
   c) $Al_2O_3 + H_2O \rightarrow$
   d) $Al_2O_3 + NaOH + H_2O \rightarrow$

7. Which reactions can be described by the following ionic equation?
   $Al^{3+} + 4OH^- \rightarrow [Al(OH)_4]^-$
   a) $Al(OH)_3 + KOH \rightarrow K[Al(OH)_4]$
   b) $AlCl_3 + 4KOH \rightarrow K[Al(OH)_4] + 3KCl$
   c) $AlCl_3 + 6KOH \rightarrow K_3[Al(OH)_6] + 3KCl$
   d) $Al(NO_3)_3 + 4NaOH \rightarrow Na[Al(OH)_4] + 3NaNO_3$

8. Calculate the sum of all coefficients in the redox reaction: $K + KNO_3 \rightarrow K_2O + N_2$
   a) 12 b) 18 c) 19 d) 20

9. Which metals have a color different from gray?
   a) gold b) copper c) silver d) cesium

10. In which reactions aluminum atoms behave as reducers?
    a) $4Al + 3O_2 \rightarrow 2Al_2O_3$
    b) $2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$
    c) $AlCl_3 + 3NaOH \rightarrow Al(OH)_3 + 3NaCl$
    d) $2Al(OH)_3\ (t°) \rightarrow Al_2O_3 + 3H_2O$

TEST FOR HOMEWORK

1. Choose metals which react with water at high temperature and produce an oxide:
   a) Mg b) Na c) Fe d) K

2. Choose reactions in which metal melts before the completion:
   a) $Li + H_2O \rightarrow$
   b) $Na + H_2O \rightarrow$
   c) $K + H_2O \rightarrow$
   d) $Cs + H_2O \rightarrow$

3. Which salts are associated with temporary water hardness?
   a) $MgCl_2$ b) $Ca(HCO_3)_2$ c) $Mg(HCO_3)_2$ d) K_2SO_4

4. Choose compound that will be formed in the reaction between solid $AlCl_3$ and solid NaOH at high temperature:
   a) $Al(OH)_3$ b) $Na[Al(OH)_4]$ c) $Na_3[Al(OH)_6]$ d) $NaAlO_2$

5. In which conditions iron turns to rust?
   a) in the presence of water
   b) in the presence of oxygen
   c) in the presence of water and oxygen
   d) in the presence of water and nitrogen

6. Which reactions are possible?
   a) $NaCl + KOH \rightarrow$ c) $KOH + HCl \rightarrow$
   b) $NaCl + AgNO_3 \rightarrow$ d) $FeCl_2 + Cl_2 \rightarrow$

7. Which reactions can be described by the following ionic equation?
   $Al^{3+} + 6OH^- \rightarrow [Al(OH)_6]^{3-}$
   a) $Al(OH)_3 + NaOH \rightarrow Na[Al(OH)_4]$
   b) $AlCl_3 + 4NaOH \rightarrow Na[Al(OH)_4] + 3KCl$
   c) $AlCl_3 + 6LiOH \rightarrow Li_3[Al(OH)_6] + 3LiCl$
   d) $Al_2(SO_4)_3 + 12NaOH \rightarrow 2Na_3[Al(OH)_6] + 3Na_2SO_4$

8. Calculate the sum of all coefficients in the redox reaction: $CaSO_4\ (t°) \rightarrow CaO + SO_2 + O_2$
   a) 5 b) 6 c) 7 d) 8

9. What particles can be found in metallic solids?
   a) neutral atoms
   b) cations
   c) anions
   d) free electrons

10. In which reactions iron atoms behave as reducers?
    a) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$
    b) $2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$
    c) $2Fe + 3Cl_2 \rightarrow 2FeCl_3$
    d) $Fe(OH)_3 + 3HCl \rightarrow FeCl_3 + 3H_2O$

EXERCISES FOR CLASSWORK

1. Write four reactions with *aluminum* containing compounds according to the chain of chemical reactions

$Al \xrightarrow{+O_2} A \xrightarrow{+HCl} B \xrightarrow{+3NaOH} C \xrightarrow{+3NaOH} D$

1. _____
2. _____
3. _____
4. _____

Write the third reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

2. Write four reactions with *iron* containing compounds according to the chain of chemical reactions

$FeO \xrightarrow{+HNO_3} A \xrightarrow{+1KOH} B \xrightarrow{+1KOH} C \xrightarrow{+H_2SO_4} D$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write the third reaction in the complete and short ionic forms:

_____

_____

3. **Determine the volume of chlorine gas reacted with 2.8 g of iron.**

_____

_____

_____

_____

4. **Calculate the mass of a salt produced after the heating together 5 g of solid sodium hydroxide and 2 g of aluminum hydroxide.**

_____

_____

_____

_____

5. **What is the mass percentage of iron turned to rust if the initial mass of iron was equal to 84 g, and the mass of iron hydroxide now is equal to 12 g.**

_____

_____

_____

6. **Calculate the volume of nitrogen released in the reaction between 18 g of nitric acid and 3 g of aluminum at high temperature.**

_____

_____

_____

_____

7. **Calculate the volume of sulfur (IV) oxide released in the reaction between 5 g of concentrated sulfuric acid and 4 g of iron at high temperature.**

_____

_____

_____

8. **Hydrochloric acid reacted with 12 g of a mixture consisting of iron and silver. The volume of hydrogen gas produced was equal to 0.6 L. What is the mass percentage of silver in that mixture?**

_____

_____

_____

_____

9. **The mass of the mixture of copper and aluminum is equal to 20 g. That mixture reacted with hydrochloric acid. The volume of hydrogen gas was equal to 13.44 L. Determine the mass percentage of copper in the mixture.**

_____

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10. **The mixture of iron (III) hydroxide and aluminum hydroxide has been heated. After the complete decomposition of hydroxides the mass of the solid remain was 31.5 % lower than the initial mass of the mixture of hydroxides. Calculate the mass percentage of aluminum hydroxide in the initial mixture and the mass percentage of iron (III) oxide in the final mixture.**

_____

_____

_____

_____

_____

EXERCISES FOR HOMEWORK

1. **Write four reactions with *iron* containing compounds according to the chain of chemical reactions**

$Fe(OH)_3 \xrightarrow{+2HCl} A \xrightarrow{+1HCl} B \xrightarrow{+AgNO_3} C \xrightarrow{t} D$

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write electron balance for the fourth reaction:

_____

_____

2. **Write four reactions with ***aluminum*** containing compounds according to the chain of chemical reactions**

Al $\xrightarrow{+HNO_3}$ A $\xrightarrow{+4NaOH}$ B $\xrightarrow{+1HCl}$ C $\xrightarrow{+3HCl}$ D

1. _____
2. _____
3. _____
4. _____

Write the second reaction in the complete and short ionic forms:

_____

_____

Write the fourth reaction in the complete and short ionic forms:

_____

_____

3. **Determine the mass of hydrogen chloride reacted with 3.3 g of iron.**

_____

_____

_____

_____

4. **Calculate the mass of a complex salt produced after putting 6 g of aluminum chloride in 200 g of the solution with the mass percentage of sodium hydroxide equal to 25 %.**

_____

_____

_____

_____

5. **What is the mass percentage of aluminum oxide on the surface of aluminum plate? That plate had a mass of 10 g. Complete dissolving in hydrochloric acid produced 12.32 L of hydrogen (in normal conditions).**

_____

_____

_____

_____

6. **Calculate the mass of ammonium nitrate formed in the reaction between 12 g of nitric acid and 2 g of aluminum at high temperature.**

_____

_____

_____

_____

7. **Calculate the volume of sulfur (IV) oxide released in the reaction between 4 g of concentrated sulfuric acid and 3 g of copper at high temperature.**

_____

_____

_____

_____

8. **Diluted sulfuric acid reacted with 20 g of a mixture consisting of iron and aluminum. The volume of hydrogen gas produced was equal to 20.67 L. What is the mass percentage of iron in that mixture?**

_____

_____

_____

_____

9. **The mass of the mixture of copper and aluminum is equal to 10 g. That mixture reacted with sodium hydroxide. The volume of hydrogen gas was equal to 6.72 L. Determine the mass percentage of copper in the mixture.**

_____

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_____

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_____

10. **The mass of the mixture made from iron and aluminum was equal to 11.49 g. The volume of chlorine gas reacted with that mixture was equal to 10 L. Determine the mass percentage of aluminum chloride in the mixture of iron and aluminum chlorides formed after the completion of the reaction.**

_____

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LESSON 12
FINAL LESSON ON THE CHEMISTRY OF ELEMENTS

1. **Write four reactions according to the following classic chain of chemical reactions and balance them:**

   $C \rightarrow CO_2 \rightarrow KHCO_3 \rightarrow K_2CO_3 \rightarrow BaCO_3$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

   Write the fourth reaction in the complete and short ionic forms:

   _____

   _____

2. **Write four reactions with *sulfur* containing compounds according to the chain of chemical reactions**

   $S \xrightarrow{+O_2} A \xrightarrow{+NaOH\ (in\ excess)} B \xrightarrow{+HCl\ (in\ excess)} C \xrightarrow{+CaO} D$

   1. _____
   2. _____
   3. _____
   4. _____

   Write the second reaction in the complete and short ionic forms:

   _____

   _____

   Write the third reaction in the complete and short ionic forms:

   _____

   _____

3. **Find the volume percentage of ammonia in its mixture with nitrogen. 5 L of that mixture reacted with 2 g of hydrogen chloride.**

   _____

   _____

   _____

   _____

4. **Find the simplest formula of a compound. The mass percentages of elements in the compound are as follows: 62.22 % of iron, 35.56% of oxygen and 2.22 % of hydrogen.**

_____

_____

_____

_____

5. **The mass of the mixture made from zinc nitrate and cobalt (II) nitrate is 12 g. That mixture has been thermally decomposed and produced 2.914 L of nitrogen dioxide. Find the mass percentage of zinc nitrate in the initial mixture.**

_____

_____

_____

_____

6. **Oxygen produced in the decomposition reaction from 10 g of potassium nitrate and 15 g of sodium nitrate has been used in the reaction of hydrogen sulfide combustion. Calculate the maximal volume of hydrogen sulfide that has been used in this process if the only one product of sulfur oxidation was sulfur dioxide.**

_____

_____

_____

_____

7. **Determine the temporary water hardness (mol/L), if 13 ml of 0.1 M solution of sodium carbonate has been used to eliminate it in the sample of water with a volume of 450 ml.**

_____

_____

_____

_____

8. **Water solution (200 g) contained the mixture of sodium fluoride and sodium chloride. That solution reacted with the excess of silver nitrate. The mass of precipitate was equal to 5 g. Remaining solution reacted with the excess of calcium bromide. The mass of precipitate was equal to 7 g. Find the mass percentage of sodium fluoride in the initial solution.**

_____

_____

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_____

9. **Find the formula of the copper ore, if the products of its complete thermal decomposition include 20 L carbon dioxide, 10 L of water vapor and 107.14 g of copper (II) oxide.**

_____

_____

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_____

10. **Phosphine obtained after the hydrolysis of 10 g calcium phosphide has been burnt completely in the excess of oxygen. Phosphorus containing product of that reaction reacted with the excess of 10 % potassium hydroxide solution. Then 2 drops of 0.2 M lithium nitrate (0.05 ml each) have been added to that solution. Calculate the mass of resulting precipitate.**

_____

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_____

_____

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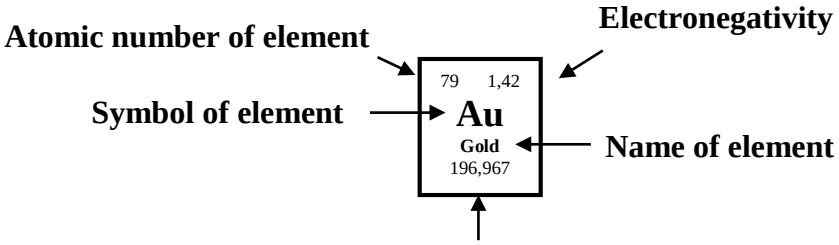
PERIODIC TABLE OF THE ELEMENTS



Period	GROUPS OF ELEMENTS																
	IA												IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 2,1 **H** Hydrogen 1.00794	IIA																2 – **He** Helium 4.0026
2	3 0,97 **Li** Lithium 6,941	4 1,47 **Be** Beryllium 9,01218											5 2,01 **B** Boron 10,811	6 2,50 **C** Carbon 12,011	7 3,07 **N** Nitrogen 14,007	8 3,50 **O** Oxygen 15,9994	9 4,10 **F** Fluorine 18,9984	10 – **Ne** Neon 20,1797
3	11 1,01 **Na** Sodium 22,9898	12 1,23 **Mg** Magnesium 24,305	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	13 1,47 **Al** Aluminum 26,9815	14 1,74 **Si** Silicon 28,086	15 2,10 **P** Phosphorus 30,9738	16 2,60 **S** Sulfur 32,066	17 2,83 **Cl** Chlorine 35,452	18 – **Ar** Argon 39,948
4	19 0,91 **K** Potassium 39,0983	20 1,04 **Ca** Calcium 40,078	21 1,20 **Sc** Scandium 44,956	22 1,32 **Ti** Titanium 47,87	23 1,45 **V** Vanadium 50,942	24 1,56 **Cr** Chromium 51,996	25 1,60 **Mn** Manganese 54,938	26 1,64 **Fe** Iron 55,845	27 1,70 **Co** Cobalt 58,933	28 1,75 **Ni** Nickel 58,693	29 1,75 **Cu** Copper 63,546	30 1,66 **Zn** Zinc 65,39	31 1,82 **Ga** Gallium 69,723	32 2,02 **Ge** Germanium 72,61	33 2,20 **As** Arsenic 74,922	34 2,48 **Se** Selenium 78,96	35 2,74 **Br** Bromine 79,904	36 – **Kr** Krypton 83,80
5	37 0,89 **Rb** Rubidium 85,468	38 0,99 **Sr** Strontium 87,62	39 1,11 **Y** Yttrium 88,906	40 1,22 **Zr** Zirconium 91,224	41 1,23 **Nb** Niobium 92,906	42 1,30 **Mo** Molybdenum 95,94	43 1,36 **Tc** Technetium [98]	44 1,42 **Ru** Ruthenium 101,07	45 1,45 **Rh** Rhodium 102,905	46 1,35 **Pd** Palladium 106,42	47 1,42 **Ag** Silver 107,868	48 1,46 **Cd** Cadmium 112,411	49 1,49 **In** Indium 114,82	50 1,72 **Sn** Tin 118,71	51 1,82 **Sb** Antimony 121,76	52 2,01 **Te** Tellurium 127,60	53 2,21 **I** Iodine 126,904	54 – **Xe** Xenon 131,29
6	55 0,86 **Cs** Cesium 132,905	56 0,97 **Ba** Barium 137,327	57 1,08 ***La** Lanthanum 138,906	72 1,23 **Hf** Hafnium 178,49	73 1,33 **Ta** Tantalum 180,948	74 1,40 **W** Tungsten 183,84	75 1,46 **Re** Rhenium 186,207	76 1,52 **Os** Osmium 190,23	77 1,55 **Ir** Iridium 192,22	78 1,44 **Pt** Platinum 195,08	79 1,42 **Au** Gold 196,967	80 1,44 **Hg** Mercury 200,59	81 1,44 **TI** Thallium 204,383	82 1,55 **Pb** Lead 207,2	83 1,67 **Bi** Bismuth 208,980	84 1,76 **Po** Polonium [209]	85 1,90 **At** Astatine [210]	86 – **Rn** Radon [222]
7	87 0,86 **Fr** Francium [223]	88 0,97 **Ra** Radium 226,025	89 1,00 **♦Ac** Actinium [227]	104 – **Rf** Rutherfor-dium [261]	105 – **Db** Dubnium [262]	106 – **Sg** Seaborgium [266]	107 – **Bh** Bohrium [264]	108 – **Hs** Hassium [265]	109 – **Mt** Meitne-rium [268]	110 – **[Uun]** [271]	111 – **[Uuu]** [272]	112 – **[Uub]** [277]	113 – **[Uut]** [282]	114 – **[Uug]** [285]	115 –	116 – **[Uuh]** [289]	117 –	118 – **[Uuo]** [293]
***Lanthanide Series**					58 1,08 **Ce** Cerium 140,115	59 1,07 **Pr** Praseody-mium 140,907	60 1,07 **Nd** Neodymium 144,24	61 1,07 **Pm** Promet-hium 144,913	62 1,07 **Sm** Samarium 150,36	63 1,01 **Eu** Europium 151,965	64 1,11 **Gd** Gadoli-nium 157,25	65 1,10 **Tb** Terbium 158,925	66 1,10 **Dy** Dyspro-sium 162,5	67 1,10 **Ho** Holmium 164,93	68 1,11 **Er** Erbium 167,26	69 1,11 **Tm** Thulium 168,934	70 1,06 **Yb** Ytterbium 173,04	71 1,14 **Lu** Lutetium 174,967
♦Actinide Series					90 1,11 **Th** Thorium 232,038	91 1,14 **Pa** Protactinium 231,035	92 1,22 **U** Uranium 238,028	93 1,22 **Np** Neptu-nium 237,048	94 1,22 **Pu** Plutonium 244,064	95 1,20 **Am** Ameri-cium 243,061	96 1,20 **Cm** Curium 247,07	97 1,20 **Bk** Berkelium 247,07	98 1,20 **Cf** Colifor-nium 251,079	99 1,20 **Es** Einsteinium 252,083	100 1,20 **Fm** Fermium 257,095	101 1,20 **Md** Mendele-vium 258,099	102 1,20 **No** Nobelium 18,9984	103 1,20 **Lr** Lawren-cium 260,105

SOLUBILITY OF INORGANIC SUBSTANCES IN WATER

	Na^+	K^+	Li^+	Ca^{2+}	Ba^{2+}	Sr^{2+}	NH_4^+	Ag^+	Mg^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Fe^{2+}	Hg^{2+}	Pb^{2+}	Fe^{3+}	Al^{3+}	Cr^{3+}	H^+
Cl^-	S	S	S	S	S	S	S	I	S	S	S	S	S	S	M	S	S	S	S
Br^-	S	S	S	S	S	S	S	I	S	S	S	S	S	M	M	S	S	S	S
I^-	S	S	S	S	S	S	S	M	S	S	S	–	S	I	I	–	S	S	S
NO_3^-	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
NCS^-	S	S	S	S	S	S	S	I	S	S	S	–	S	I	I	S	S	S	S
SO_4^{2-}	S	S	S	M	I	I	S	M	S	S	S	S	S	S	I	S	S	S	S
F^-	S	S	M	I	M	S	S	S	I	S	S	S	M	–	I	M	M	S	S
CH_3COO^-	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
S^{2-}	S	S	S	M	I	I	S	I	I	I	I	I	I	I	I	–	–	–	S
SO_3^{2-}	S	S	S	I	I	I	S	I	M	I	I	I	I	–	I	–	–	–	S
CO_3^{2-}	S	S	M	I	I	I	S	I	I	I	I	I	I	I	I	–	–	–	S
SiO_3^{2-}	S	S	S	I	I	I	–	I	I	I	I	I	I	–	I	–	–	–	I
PO_4^{3-}	S	S	I	I	I	I	S	I	I	I	I	I	I	I	I	I	I	I	S
NO_2^-	S	S	S	S	S	S	S	M	S	–	–	–	–	–	–	–	–	–	S
HS^-	S	S	S	S	S	S	S	–	S	–	–	–	–	–	–	–	–	–	S
HSO_3^-	S	S	S	S	S	S	S	–	S	–	–	–	–	–	–	–	–	–	S
HPO_4^{2-}	S	S	–	I	I	I	S	S	M	I	–	–	I	–	M	–	–	–	S
$H_2PO_4^-$	S	S	S	S	S	S	S	S	S	S	S	–	S	–	–	–	–	–	S
OH^-	S	S	S	M	S	S	S	–	I	I	I	I	I	–	I	I	I	I	

S — Soluble; I — Insoluble; M — Marginally soluble

ELECTROCHEMICAL SERIES OF METALS

$\frac{Me^{n+}}{Me^0}$	$\frac{Li^+}{Li^0}$	$\frac{K^+}{K^0}$	$\frac{Sr^{2+}}{Sr^0}$	$\frac{Ba^{2+}}{Ba^0}$	$\frac{Ca^{2+}}{Ca^0}$	$\frac{Na^+}{Na^0}$	$\frac{Mg^{2+}}{Mg^0}$	$\frac{Al^{3+}}{Al^0}$	$\frac{Zn^{2+}}{Zn^0}$	$\frac{Cr^{2+}}{Cr^0}$	$\frac{Fe^{2+}}{Fe^0}$	$\frac{Ni^{2+}}{Ni^0}$	$\frac{Sn^{2+}}{Sn^0}$	$\frac{Pb^{2+}}{Pb^0}$	$\frac{2H^+}{H_2^0}$	$\frac{Bi^{3+}}{Bi^0}$	$\frac{Cu^{2+}}{Cu^0}$	$\frac{Ag^+}{Ag^0}$	$\frac{Hg^{2+}}{Hg^0}$
e^0,V	–3.04	–2.92	–2.89	–2.90	–2.87	–2.71	–2.37	–1.70	–0.76	–0.74	–0.44	–0.25	–0.14	–0.13	0	+0.21	+0.34	+0.80	+0.85

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