50<sup>th</sup> CHEMISTRY OLYMPIAD
**Final National Competition**

2003

# ESTONIA

**PROBLEMS**

**FORM X**

**1.** Piglet has five balloons. Three of them are filled with the main constituents of the atmospheres of Venus (**A**), Saturn (**B**) and Mercury (**C**). The other two balloons are filled with the compounds which constitute the clouds on the planets Venus (**D**) and Saturn (**E**). The balloon with the compound **A** falls on the floor, meanwhile the balloons with **B** and **E** fly up to the ceiling. The compounds **C** and **D** can't be gaseous at the room temperature; therefore these balloons are not inflated. **D** is a heavy oily liquid, which has destroyed the balloon and began to char the floor in Piglet's house. The compound **C** can be cut with the knife. It floats on the surface of water. In the reaction of **C** with water the gas **B** and a solution of **F** are formed. A big piece of **C** can burst into yellow flame on the surface of water. The compound **F** can suppress the corrosive action of **D** forming a normal salt **J**. If the gas **A** is passed through the solution of **F**, a compound **G** is formed, which is an

important constituent of baking powder. **G** neutralizes **D** as well forming a normal salt **J** with evaluation of the gas **A**. The compound **E** has a characteristic caustic odour. If **A** and **E** are passed through water an acid salt **H** is formed. **H** is a component of baking powder as well and neutralizes **D** forming a normal salt **I**, which is used as fertilizer in agriculture.

**a) i)** What are the main constituents of the atmospheres of the planets Venus, Saturn and Mercury? **ii)** What compounds constitute clouds on Venus and Saturn? Give formulas and names of the compounds **A – E**.

**b)** Which one of the inflated balloons do you consider to be the safest present for Piglet's friend Eeyore? Why are the other balloons dangerous?

**c)** Why **i)** does the balloon with the compound **A** fall on the floor and **ii)** why do the balloons with **B** and **E** fly up to the ceiling?

**d)** Give formulas and names of compounds **F**, **G**, **H**, **I** and **J**.

**e)** Write equations for the following reactions: **i)** $C + H_2O \rightarrow$; **ii)** $F + D \rightarrow$; **iii)** $F + A \rightarrow$; **iv)** $G + D \rightarrow$; **v)** $A + E + H_2O \rightarrow$; **vi)** $H + D \rightarrow$.


**2.** By utilization of a chromatograph 139.88 g of contacts covered with gold were soldered. When the contacts were treated with concentrated nitrous acid, their base made of copper dissolved. During this process $NO_2$ evaluated and 32.61 g of an insoluble residue remained. After washing a grey monohydrate of metastannous acid out from this residue, 5.08 g of pieces of the gold foil were obtained. These pieces were fused in the muffle-furnace in the air atmosphere. The copper content in the formed gold alloy was 5.56% and there was also 0.636 g of copper (II) oxide formed in the crucible.

**a)** Write equations of the reactions: **i)** $Cu + HNO_3 conc. \rightarrow$;

**ii)** $Sn + HNO_3 conc. \rightarrow$.

**b)** Which one of tin compounds has the same qualitative and quantitative composition as the compound in the reaction **a) ii)**?

**c)** Calculate percentage of tin in the soldered contacts.

**d)** Calculate percentage of gold in the gold foil.

**3.** Estonian shale consists of an organic part (kerogen) and a mineral part. From the compounds of the mineral part mainly carbonates decompose as thermally as under treatment with hydrochloric acid. After combustion of 100.0 g of the shale-dust 53.0 g of ashes was obtained. When the same amount of the shale was treated with hydrochloric acid 6.74 liters of carbon dioxide evaluated. 1.9 g of water, 5.6 g of gases, shale-oil and a solid residue are formed after dry distillation of 100.0 g of the shale at 500 $^o$C.

**a)** Calculate percentage by weight of **i)** kerogen and **ii)** mineral substances in  the shale, if carbonates decompose totally by combustion.

**b)** Calculate the yield of the shale-oil obtained from shale, if the yield of the shale-oil from kerogen is 66%.

**c)** Graphite is formed from a certain part of kerogen by dry distillation. What  part (in percents) of **i)** shale and **ii)** kerogen is converted into graphite by dry distillation?

**4.** A certain amount of the mixture of copper, iron and aluminium powders was treated with 40.0 g of NaOH in one case (a complex compound with four hydroxyl groups is formed), with 37.4 dm$^3$ of chlorine in other case and with 1035 cm$^3$ of 10.0% solution of HCl (1.10 g/cm$^3$) in the third case.

**a)** Write equations for the reactions of the components of the mixture with     **i)** sodium hydroxide, **ii)** chlorine and **iii)** hydrochloric acid.

**b)** Calculate the masses of **i)** Al, **ii)** Fe and **iii)** Cu in the initial mixture.

**5.** The oxidizers **A**, **B** and **C** are used in municipal wastewater purification systems. Their characteristic data is given in the following table:

| | Oxygen content | Reactivity | Health hazard | Supplied form | Reactions | | |
|---|---|---|---|---|---|---|---|
| | | | | | A | B | C |
| **A** | 94.1% | 1 | 2 | 35–50% water solution | | + | + |
| **B** | 0% | 2 | 4 (toxic) | pressurized cylinders | + | | – |
| **C** | 40.5% | 2 | 3 (dust inhalation hazard) | crystalline dark-coloured substance | + | – | |

All these oxidizers eliminate unpleasant odours of wastewaters by oxidizing hydrogen sulfide. The compound **B** oxidizes hydrogen sulphide maximally forming two acids. Sulfide-ion is oxidized at the same extent if it's treated with the oxidizer **C** in alkali medium, whereas the degree of oxidation of **C** decreases by three. If hydrogen sulfide is treated with oxidizers **A** or **C** in acidic medium, a pale yellow precipitate is formed.

**a) i)** Give formulas and names of the compounds **A**, **B** and **C** and

   **ii)** check if their oxygen contents correspond to the data given in the table.

**b)** Write equations of the following reactions: **i) A + B** → simple compound;     and **ii) A + C + $H_2SO_4$** → simple compound, whereas the degree of oxidation of the oxidizing element in the compound **C**

degreases by five.

**c)** Write equations of the following reactions: **i)** $H_2S + H_2O + B \rightarrow$;

**ii)** $S^{2-} + C + + H_2O \rightarrow$;  **iii)** $H_2S + A \rightarrow$;  **iv)** $H_2S + H_2SO_4 + C \rightarrow$.

**d)** Calculate the amount of NaOH (in moles) which is needed to neutralize the solution formed, if $H_2S$ is oxidized by 1 mole of the compound **B**.

**e)** Write equations of the reactions which explain over-expenditure of the alkali solution in case oxidizer **B** is overdosed.

**6.** If food oxidation were fast and complete in the organism, a few pieces of sugar would be enough to cause inadmissible overheating of the organism. Sugar oxidation in our bodies is a long complicated biochemical process. According to the Hess's law the total energy change for a chemical reaction depends only on initial and final states of the system. Thus it can be calculated from thermodynamic data.

**a)** Write equation of the total oxidation of sucrose.

**b)** Calculate the total energy change for this reaction, if enthalpies of formation $\Delta H_f$ for the compounds taking part in the reaction are the following:

$C_{12}H_{22}O_{11}(s)$ = -2222.0 kJ/mol; $CO_2(g)$ = -393.5 kJ/mol;

$H_2O(l)$ = -285.8  kJ/mol; $O_2$ = 0 kJ/mol.

**c)** How many grams of sugar should be oxidized to produce the amount of energy needed to evaporate exactly one litre of water?

$\Delta H_f(H_2O(g))$ = -241.8 kJ/mol.
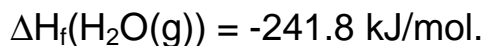
**FORM XI**

**1.** When Estonian shale is heated without air access, shale-oil distillation occurs. This shale-oil contains more than 1000 compounds with an average molecular mass of 24$\underline{0}$. The obtained oil contains approximately 6.9% of oxygen, 82% of carbon and 11% of hydrogen. The condensation of the gases formed by dry distillation results also in liquation of water vapours, in which some polar compounds are dissolved, e g two-atomic phenols – resorcines, in which hydroxyl groups are in *meta*-position.

**a)** Estimate the shale-oil molecule's simplest formula. Consider the percentage    to be precise.

**b)** Express the numbers of atoms in the shale-oil formula in round numbers; and write empirical formula of the saturated compound according to the number of carbon atoms in the form of   **i)** ketone and **ii)** alcohol.

**c)** Draw graphic structures of the following compounds dissolved in water: **i)** 5-methyl resorcine, **ii)** 5-ethyl resorcine and **iii)** 2,5-dimethyl resorcine.

**d)** Draw graphic structures of the following compounds contained in the shale-oil:  **i)** decane, **ii)** 2-decanone, **iii)** pentyl cyclohexane, **iv)** 1,7-octadiene,  **v)** 3-methyl phenol and    **vi)** heptane dicarboxylic acid.


**2.** The acids **A**, **B**, **C** and **D** contain two nonmetals **X** and **Y**, besides hydrogen. Dehydration of these acids results in formation of either gases **E** and **F** or a five-atomic liquid **G**, which contains 47.0% of the element **Y**. The compounds **E**, **F** and **G** have the same qualitative composition. The acid **A** can exist only in a very dilute solution, further concentration of which results in the eduction of water from the acid **A**.  Dehydration of the acids **B** and **C** goes by heating with $H_2SO_4$. If **D** is heated with $P_4O_{10}$, two molecules of water are eliminated from 1 molecule of this acid and the compound **G** is formed. Exactly 0.04 moles of NaOH is consumed in

neutralization of 2080 mg of the acid **D**. The compound **E** usually doesn't have acidic properties. However it reacts with NaOH at high temperatures forming a salt **I** of the acid **B**. When heated till 400 $^{\circ}$C, two molecules of the salt **I** form sodium salt of the acid **C** with evaluation of hydrogen. If a molecule of the compound **G** reacts with 2 molecules of methanol, methyl ester of the acid **D** is formed.

**a)** Determine elements **X** and **Y**, as well as compounds **E** and **F** (formulas and names).

**b)** Estimate an empirical formula of the compound **G** and give its structural formula.

**c)** From the titration data estimate the molar mass of the acid **D** and prove its structural formula.

**d)** Write structural formulas of the compounds **A**, **B** and **C**; write equations of their dehydration and dehydration of the acid **D**.

**e)** Write equations of the reactions: **i) E** + NaOH $\rightarrow$ **I**; **ii) I** $\rightarrow$ H$_2$; **iii) G** + CH$_3$OH $\rightarrow$.


**3.** There are large deposits of the mineral **A** in the north-east of Estonia. If this mineral is heated with sand and coal in the furnace, a compound **B** is produced. A long heating of the compound **B** results in formation of a red compound **C**. The solid **B** shines in the air with the green light and may ignite. Having heard a lot about chemistry but not studied it yet, Peter explained to his friends that the reason for the luminescence of the compound **B** is special 3p orbitals. To prove that he gave five examples:

**1)** The compound **B** doesn't shine under water because water dissolves these special 3p orbitals.

**2)** If one part of this water solution is added to the equivalent part of the 2 M solution of hydrochloric acid, pH of the resulting solution becomes zero.

**3)** If alkali solution is added to the compound **B**, one molecule of **B** reacts with three molecules of NaOH and three molecules of water forming three molecules of the compound **D** and one molecule of the gas **F**. The gas **F** sublimes in the air because of the sticking of 3p orbitals to its molecules.

**4)** The compound **F** dissolves in water without considerable change in pH of the solution. However, pH of hydrochloric acid solution decreases if the gas **F** is passed through it (because of interacting of 3p orbitals with each other).

**5)** Similar to 2p orbitals of nitrogen, free 3p orbitals separated from the mineral **A** by sulfuric acid promote the growth of herbs.

**Notice**: If someone hasn't realized the Peter's mistake yet, the orbitals can't be separated from the substance as these are the space where an electron can be with the certain probability.

**a)** Write **i)** equations for the reaction of obtaining the compound **B** and

   **ii)** formulas and names of the compounds **A**, **B**, **C** and **F**.

**b)** Write corresponding equations for the example 1–5 or give explanations.


**4.** The students were given an experimental work. They were asked to prepare a solution of $CuSO_4$ from blue copperas ($CuSO_4·5H_2O$). Then 1.22 M solution of $NaHCO_3$ is added to the prepared solution. The formed suspension is heated at 80 $^o$C until evaluation of the gas ceases. After that the vessel with the mixture is cooled in the air and then in crystallizer filled with water. The formed bluish-green precipitate **A** is filtered, washed, dried and weighed. If the compound **A** is heated a gas **B** evaluates. **B** is then passed through the lime-water, whereby a precipitate is formed which dissolves in excess of the gas **B**. After incineration a black substance **C** is left in the tube. The compound **C** is

then reduced to copper by $NH_3$ at high temperature. Heating of **A** results also in formation of water.

**a)** Give formulas and names of the compounds **A**, **B** and **C**.

**b)** Write equations of the reactions: **i)** $CuSO_4 + NaHCO_3 \rightarrow$; **ii)** $A \xrightarrow{\phantom{x}^{o}t^{o}t\phantom{x}}$;

   **iii)** $Ca(OH)_2 + B \rightarrow$; **iv)** **B**(excess) $\rightarrow$; **v)** **C** + $NH_3$.

**c)** Calculate **i)** the mass of blue copperas and **ii)** the volume of water needed for the preparation of 27.8 g of 13.0% solution of $CuSO_4$.

**d)** Calculate the volume of 1.22 M solution of $NaHCO_3$ consumed in synthesis.

**e)** Calculate the yield percentage, if 2.4 g of **A** was obtained.

**5.** 250 ml of a solution containing $Ag^+$, $Cu^{2+}$ and $Cr^{3+}$ ions was obtained from 25$\underline{0}$0 mg of an alloy. From 1/25$^{th}$ part of this solution first copper and silver were eliminated, and then $Cr^{3+}$ ions were oxidized to $CrO_4^{2-}$ ions in alkali medium by hydrogen peroxide. 24.00 ml of 0.1500 M acidified solution of $Fe^{2+}$ was added to the solution obtained. And 31.00 ml of 0.0196 M solution of $KMnO_4$ was consumed in back titration $(5Fe^{2+} \Leftrightarrow 1KMnO_4)$. 9 min 35 sec is needed to precipitate the metals from 50.00 ml of initial solution by electrolysis with the current of 2.36 A.

**a)** Write equations of the reactions between ions: **i)** $Cr^{3+} + H_2O_2 + OH^- \rightarrow$;

   **ii)** $CrO_4^{2-} + Fe^{2+} + H^+ \rightarrow$; **iii)** $MnO_4^- + Fe^{2+} + H^+ \rightarrow$.

**b)** From the titration data calculate the mass of chromium contained in the alloy.

**c)** Calculate masses of Ag and Cu in the alloy using the mass of chromium found and the amount of electricity consumed

  (F = 96485 A·s/mol).

**6.** The three following solution were obtained by mixing the solutions:

**A:** 100 cm$^3$ 0.05 M $C_6H_5COOH$ (benzoic acid) + 30 cm$^3$ 0.08 M NaOH;

**B:** 0.2 dm$^3$ 0.4 M HCl + 0.2 dm$^3$ 0.5 M $NH_3 \cdot H_2O$;

**C:** 10 cm$^3$ 0.4 M HCl + 12 cm$^3$ 0.4 M NaOH

$K_A(C_6H_5COOH) = 6.5 \cdot 10^{-5}$ mol/dm$^3$; $K_B(NH_3 \cdot H_2O) = 1.79 \cdot 10^{-5}$ mol/dm$^3$;

$K_W = 10^{-14}$ mol$^2$/dm$^6$ (usually the units are not given). The precision of initial data allows estimating of pH value with the accuracy of 0.1 units.

**a)** From the dissociation constant of the acid, deduce a formula for the estimation of the equilibrium concentration of hydrogen ions [H$^+$] contained in the solution prepared from a weak acid and its salt.

**b)** For the solutions **A**, **B** and **C: i)** write equations of the reactions taking place in the solutions; **ii)** calculate initial and final amounts of all the compounds (except $H_2O$); **iii)** calculate pH values of the solutions.

## FORM XII

**1.** Compounds of the inorganic part of Estonian shale can be divided into constituents of clay-sand and carbonates. Components of the clay-sand are $Al_2O_3$, $K_2O$, $FeS_2$, $Fe_2O_3$, $H_2O$, $SO_2$ and a component **X**. The content of the latter one in the clay-sand is about 60%. Components of the carbonate part are CaO – 48.1%, FeO – 0.2%, $CO_2$– 45.1% and a component **Y**. Ashes from shale combustion is used for neutralization of soils and in production of cement. The smoke of the burning shale contains a compound which causes acid rains. After reaction with other products of combustion contained in the smoke and after oxidation in the air, this compound forms a solid substance which falls out onto the

surface of the ground and is identical to the congealed gypsum. Kerogen constitutes the organic part of the shale.

**a)** What are the name and the formula of the component **X**.

**b) i)** Estimate the molar mass of the component **Y** and **ii)** give its formula and name.

**c)** What kind of soils needs treatment with the shale ashes and which compound improves their properties?

**d)** Write down two main oxides contained in cement.

**e)** From which parts of the shale (kerogen, clay-sand, carbonates) are three compounds formed which are initial in production of gypsum?

**f)** Write reactions of the formation of congealed gypsum: **i)** formation of acid rains; **ii)** its oxidation; **iii)** formation of gypsum.


**2.** When a hard binary compound **A** was heated with a hard simple compound **B** and a gaseous simple compound **C**, a readily volatile binary five-atomic liquid compound **D** and a colourless highly toxic diatomic compound **E** are formed.  The compound **A** contains 40% of oxygen and is used as a white pigment in dies. The liquid **D** is readily hydrolyzed and is used for fog imitation. If hydrolysis is complete, the compound **A** is formed. A simple compound **X** can be obtained as a result of the reaction of Mg with vapors of the compound **D**. Reduction of **D** by a simple compound **F** gives HCl and a violet compound **G** (in molar ratio 1:1). When reacted with NaOH solution, the compound **G** forms an insoluble oxide-monohydrate **H**. The latter is not a redox reaction. As *meta-* as *ortho*-salts can be obtained by fusion of the compound **A** with metal oxides or alkali.

**a)** Estimate the molar mass of the compound **A** and determine the simple compound **X**.

**b)** Write formulas and names of the compounds **A** – **H**.

**c)** Write equations of the following reactions: **i) A +B +C→; ii) D +H₂O→;**

**iii) D** + Mg →; **iv) D** + F →; **v) G** + NaOH →; **vi) A** + CaO → *meta*-compound (give its name); **vii) A** + NaOH → *ortho*-compound (give its name).

**3.** 176.3 mg of the compound **X** was burned in the oxygen atmosphere. The hot products of the combustion were first passed through a hydroscopic magnesium perchlorate powder and then absorbed in a barium hydroxide solution. The mass of $Mg(ClO_4)_2$ increased by 216.2 mg. And 1.973 g of a white precipitate were separated from the solution of $Ba(OH)_2$. An industrial production of the compound **X** is based on the reaction of **A** with **B** in the presence of an acidic catalyst. The toxic liquid **A** is obtained by a catalytic reduction of carbon monoxide by hydrogen. If the compound **A** reacts with concentric sulfuric acid, an ester **C** with an empiric formula $C_2H_6O_4S$ is formed. The compound **D** is formed in the reaction of **C** with potassium iodide (nucleophylic substitution). Two molecules of water combine with a molecule of the compound **B** in acidic medium forming a compound **E** which has three identical methyl groups. The compound **E** reacts with sodium forming a salt **F** with evaluation of hydrogen. As a result of the reaction of **C** with **F**, the compound **X** and sodium methyl sulfate are formed.

**a)** Estimate the simplest empirical formula of the compound **X**.

**b)** Write simplified structural formulas of the compounds **X** and **A** – **F**.

**c)** Write equations of the reactions: **i)** CO + H₂ →; **ii) A** + H₂SO₄ →;

**iii)** 1**C** + 1KI →; **iv)** 1**B** + 1H₂O →; **v) E** + Na →; **vi) C** + **F** →

**vii) A** + **B** →

**4.** 25.0 ml of 1.20 M solution of NaOH was consumed for neutralization of 1.71 g of a carboxylic acid (doesn't contain any other functional groups). If the same acid is heated, a compound with the carbon content of 50% is formed.

**a)** Estimate the molar mass of the monoprotic carboxylic acid using results of the titration.

**b)** Give structural formulas of three possible carboxylic acids which satisfy the results of the titration.

**c)** What compound is formed from a carboxylic acid under treatment with a water-retention agent?

**d)** Draw the planar structural formula of the compound (carbon content 50%) which is formed by heating the carboxylic acid with the largest molar mass found in paragraph **b)**.

**5.** Spontaneous decomposition of hydrogen peroxide is a first order reaction. The reaction progress is watched by determination of the amount of hydrogen peroxide left in certain intervals of time. In an acidified solution $H_2O_2$ reacts with $KMnO_4$ instantly. In practice an exact volume of $H_2O_2$ in a certain period of time is added to a measured volume of $KMnO_4$ solution with known concentration. Then the amount of $KMnO_4$ reacted is determined by back titration with a solution of $Fe^{2+}$. The amount of hydrogen peroxide left after spontaneous decomposition is proportional to the amount of $KMnO_4$ consumed in the reaction (given in the table):

| Time (min) | 0 | 5 | 10 | 20 | 30 |
|---|---|---|---|---|---|
| $n(KMnO_4)$ (mmol) | 46.1 | 37.1 | 29.8 | 19.3 | 12.5 |

$$\ln(c_0/c_t) = k \cdot t$$

**a)** Write equations of the reactions: **i)** $H_2O_2$ decomposes $\rightarrow$; **ii)** $H_2O_2$ + $H_2SO_4$ + $KMnO_4 \rightarrow$;   **iii)** $FeSO_4$ + $H_2SO_4$ + $KMnO_4 \rightarrow$.

**b)** From the data given above calculate the rate constants and their average.

**c)** Calculate the half-life period of the reaction of decomposition of $H_2O_2$.

**d)** Calculate the amount of $KMnO_4$ consumed in the titration of $H_2O_2$, if the time passed from the beginning of the reaction is 50 minutes.


**6.** The following processes take place on the Sun:

$$^1H + {}^1H = {}^2H + \beta^+ + \upsilon$$

$$^2H + {}^1H = {}^3He + \gamma$$

$$^3He + {}^3He = {}^4He + 2\,{}^1H$$
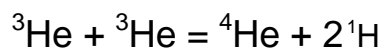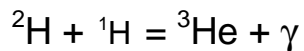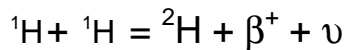
where    $\beta^+$,   $\upsilon$   and    $\gamma$    are positron, neutrino and gamma-ray respectively.

**a)** Write the net equation of the reaction of hydrogen "combustion" on the Sun.

**b)** Calculate the mass defect for the formation of one atom of $^4He$.

**c)** Calculate **i)** the mass defect (kg) and **ii)** energy released by "combustion" of 5.000 g of hydrogen.

**d)** Calculate **i)** combustion enthalpy for 5.0 g of hydrogen; **ii)** how many times the energy released by "combustion" of hydrogen on the Sun exceeds energy estimated in the paragraph **i)**.

   $m(^1H) = 1,00727$ a.u.m.; $m(^4He) = 4,00273$ a.u.m.;

   $m(\beta^+) = 0,0005486$ a.u.m..

   $E = m \cdot c^2$; $c = 3,0 \cdot 10^8$ m/s; $\Delta H_f^0 (H_2O) = -286$ kJ/mol;

   the mass of neutrino is negligibly small and gamma-ray doesn't have a mass of rest.

# Solutions

## FORM X

**1. a) i) A** – $CO_2$, carbon dioxide

**B** – $H_2$, hydrogen

**C** – Na, sodium

**ii) D** – $H_2SO_4$, sulfuric acid

**E** – $NH_3$, ammoniac

**b)** The balloon filled with $CO_2$ is safe, $H_2$ is explosive hazardous and $NH_3$ irritates respiration.

**c)** $M_r$(air) = 29 < $M_r$ ($CO_2$)= 44,        falls on the floor

$M_r$(air) = 29 > $M_r$($H_2$) = 2,                  flies up to the ceiling

$M_r$(air) = 29 > $M_r$($NH_3$) = 17,        flies up to the ceiling

**d) F** – NaOH, sodium hydroxide

**G** – $NaHCO_3$, sodium bicarbonate

**H** – $NH_4HCO_3$, ammonium bicarbonate

**I** – $(NH_4)_2SO_4$ ammonium sulfate

**J** – $Na_2SO_4$, sodium sulfate

**e) i)** $2Na + 2H_2O = 2NaOH + H_2\uparrow$

**ii)** $2NaOH + H_2SO_4 = Na_2SO_4 + 2H_2O$

**iii)** $NaOH + CO_2 = NaHCO_3$

**iv)** $2NaHCO_3 + H_2SO_4 = Na_2SO_4 + 2CO_2 + 2H_2O$

**v)** $CO_2 + NH_3 + H_2O = NH_4HCO_3$

**vi)** $2NH_4HCO_3 + H_2SO_4 = (NH_4)_2SO_4 + 2CO_2 + 2H_2O$


**2. a) i)** $Cu + 4HNO_3(conc) = Cu(NO_3)_2 + 2NO_2 + 2H_2O$

II      (-)     0

$Cu + 2e^- = Cu$      1

IV     (-)     V

$N - 1e^- = N$      2

**ii)**    $Sn + 4HNO_3(conc) = H_2SnO_3 \cdot H_2O + 4NO_2$

0      (-)     IV

$Sn - 4e^- = Sn$      1

V     (-)     IV

$N + 1e^- = N$      4
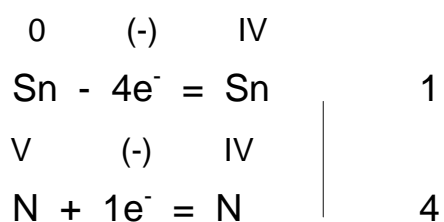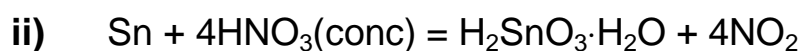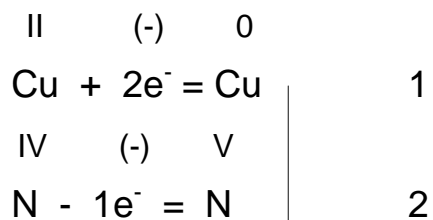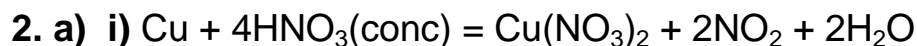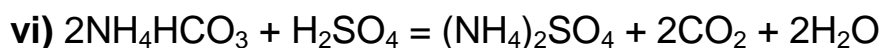
**b)**   $Sn(OH)_4$, tin(IV) hydroxide

**c)**    $m(H_2SnO_3 \cdot H_2O) = 32.61\ g - 5.08\ g = 27.53\ g$

$M_r (H_2SnO_3 \cdot H_2O) \Leftrightarrow A_r(Sn)$

186.6             118.6

$\textbf{\%(Sn)} = 27.53\ g \cdot 118.6 \cdot \dfrac{1}{186.6} \cdot \dfrac{1}{139.88\ g} \cdot 100 = \textbf{12.51}$


**d)**   $M_r(CuO) \Leftrightarrow A_r(Cu)$

79.5             63.5

$m[Cu,\ in\ copper(II)\ oxide] = 0.636\ g \cdot 63.5 \cdot \dfrac{1}{79.5} = 0.508\ g$

$m(Cu,\ in\ the\ formed\ alloy) = (5.08\ g - 0.508\ g) \cdot 0.0556 = 0.254\ g$

$\textbf{\%(Au)} = (5.08\ g - 0.508\ g - 0.254\ g) \cdot \dfrac{1}{5.08\ g} \cdot 100 = \textbf{85.0}$


**3. a)** The amount of the $CO_2$ evaluated from the mineral part by combustion is the same as by reaction with hydrogen chloride .

$$m(CO_2) = 6.74\,\text{dm}^3 \cdot \frac{1\,\text{mol}}{22.4\,\text{dm}^3} \cdot 44\,\text{g/mol} = 13.2\ \text{g}$$

**i)** %(kerogen) = (100 g – 13.2 g – 53.0 g) $\cdot \dfrac{1}{100\,\text{g}} \cdot 100$ = **33.8**

**ii)** %(mineral part) = (100 g – 33.8 g) $\cdot \dfrac{1}{100\,\text{g}} \cdot 100$ = **66.2**

or    mineral part = 100% - 33.8% = 66.2%

**b) %yield**(oil from shale) = 0.338 · 0.66 · 100 = **22.3**

**c)** m(solid residue after dry distillation) = 100 g – 1.9 g –5.6 g –22.3 g=

= 70.2 g

**i)** %(graphite) = (70.2 g – 66.2 g) $\cdot \dfrac{1}{100\,\text{g}} \cdot 100$ = **4.0**

**ii)** %(graphite, from kerogen) = 4 g $\cdot \dfrac{1}{33.8\,\text{g}} \cdot 100$ = 11.8 ≈**12**


**4. a) i)** 2Al + 2NaOH + 6H$_2$O = 2Na[Al(OH)$_4$] + 3H$_2$↑

**ii)** Cu + Cl$_2$ = CuCl$_2$

2Fe + 3Cl$_2$ = 2FeCl$_3$

2Al + 3Cl$_2$ = 2AlCl$_3$

**iii)** 2Al + 6HCl = 2AlCl$_3$ + 3H$_2$↑

Fe + 2HCl = FeCl$_2$ + H$_2$↑

**b) i)** 2Al $\Leftrightarrow$ 2NaOH
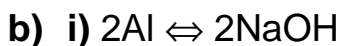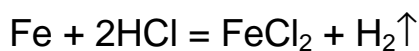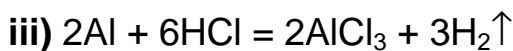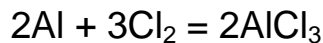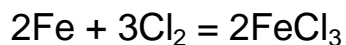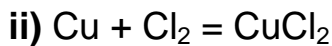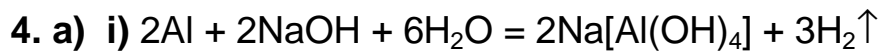
**m(Al)** = $\dfrac{2}{2} \cdot 40.0\,\text{g} \cdot \dfrac{1\,\text{mol}}{40.0\,\text{g}} \cdot 26.98\,\text{g/mol}$ = 26.98 g ≈**27.0 g**

**ii)** n(HCl, initial) = 1035 cm$^3$ · 1.10 g/cm$^3$ · 0.100 $\cdot \dfrac{1\,\text{mol}}{36.5\,\text{g}}$ = 3.12 mol

6HCl $\Leftrightarrow$ 2Al
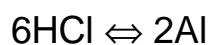
N(HCl)$_{Al}$ = $\dfrac{6}{2}$ · 1.00 mol = 3.00 mol

$n(HCl)_{Fe}$ = 3.12 mol – 3.00 mol = 0.12 mol

2HCl ⟺ Fe
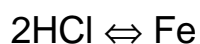
**m(Fe)** = $\frac{1}{2}\cdot 0.12\,\text{mol}\cdot 55.85\,\text{g/mol}$ = 3.35 g ≈ **3.4 g**

**iii)** $n(Cl_2, \text{initial})$ = 37.4 dm$^3$ $\cdot \dfrac{1\,\text{mol}}{22.4\,\text{dm}^3}$ = 1.6696 mol ≈ 1.67 mol

2Al ⟺ 3Cl$_2$
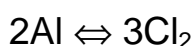
$n(Cl_2)_{Al}$ = $\frac{3}{2}$ · 1.00 mol = 1.50 mol

2Fe ⟺ 3Cl$_2$

$n(Cl_2)_{Fe}$ = $\frac{3}{2}$· 0.060 mol = 0.090 mol

$n(Cl_2)_{Cu}$ = 1.67 mol – 1.50 mol – 0.090 mol = 0.08 mol

Cu ⟺ Cl$_2$

**m(Cu)** = 0.08 mol · 63.55 g/mol = 5.08 g ≈ **5,1 g**


**5. a) i) A** – $H_2O_2$, hydrogen peroxide

　　　**B** – $Cl_2$, chlorine

　　　**C** – $KMnO_4$, potassium permanganate

**ii) %(O$_2$, H$_2$O$_2$)** = $\frac{32}{34}\cdot 100$ = **94.1**

**%(O$_2$, KMnO$_4$)** = $\frac{64}{158}\cdot 100$ = **40.5**

**b) i)** $H_2O_2 + Cl_2 = 2HCl + O_2$

　2·(-I)　　(-)　　2·0

　$O_2$ - 2e$^-$ = 2O

　　2·0　　(-)　　2·(-I)

　$Cl_2$ + 2e$^-$ = 2Cl$^-$
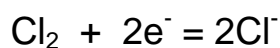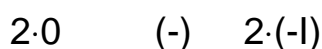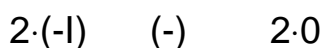
**ii)** $5H_2O_2 + 2KMnO_4 + 3H_2SO_4 = 1K_2SO_4 + 2MnSO_4 + 5O_2 + 8H_2O$

$$2 \cdot (-I) \quad (-) \quad 2 \cdot 0$$
$$O_2 - 2e^- = 2O \quad \bigg| \quad 5$$
$$VII \quad (-) \quad II$$
$$Mn + 5e^- = Mn \quad 2$$

**c)** **i)** $H_2S + 4H_2O + 4Cl_2 = 8HCl + 1H_2SO_4$

$$-II \quad (-) \quad VI$$
$$S - 8e^- = S \quad \bigg| \quad 1$$
$$2 \cdot 0 \quad (-) \quad 2 \cdot (-II)$$
$$Cl_2 + 2e^- = 2Cl \quad 4$$

**ii)** $3S^{2-} + 8KMnO_4 + 4H_2O = 3SO_4^{2-} + 8MnO_2 + 8KOH$

$$-II \quad (-) \quad VI$$
$$S^{2-} - 8e^- = S \quad \bigg| \quad 3$$
$$VII \quad (-) \quad IV$$
$$Mn + 3e = Mn \quad 8$$

**iii)** $H_2S + H_2O_2 = S + 2H_2O$

**iv)** $5H_2S + 2KMnO_4 + 3H_2SO_4 = 5S + K_2SO_4 + 2MnSO_4 + 8H_2O$

$$-II \quad (-) \quad 0$$
$$S - 2e^- = S \quad \bigg| \quad 5$$
$$VII \quad (-) \quad II$$
$$Mn + 5e^- = Mn \quad 2$$

**d)** $1H_2S \Leftrightarrow 10H^+ \Leftrightarrow 10NaOH$; and from the equation c) i)

$H_2S \Leftrightarrow 4\,Cl_2$

$n(NaOH) = \dfrac{10}{1} \cdot \dfrac{1}{4} \cdot \mathbf{1mol = 2.5mol}$

**e)** $Cl_2 + H_2O = HCl + HClO$

$HCl + NaOH \rightarrow NaCl + H_2O$,

$HClO + NaOH \rightarrow NaClO + H_2O$
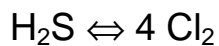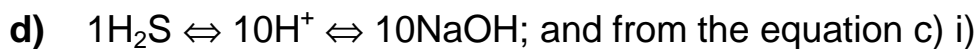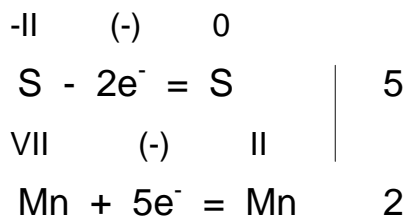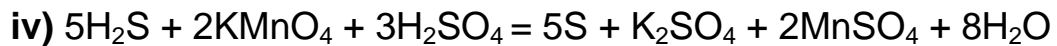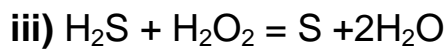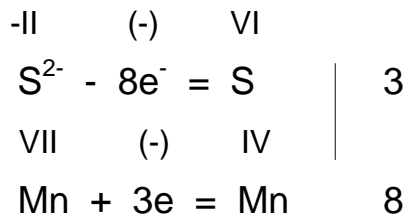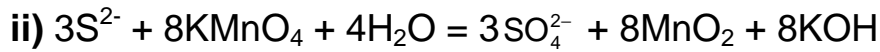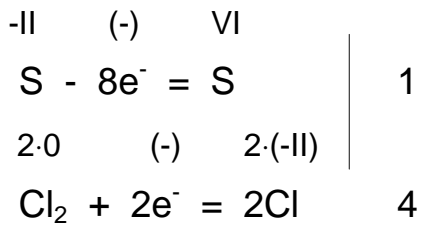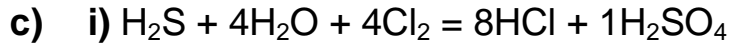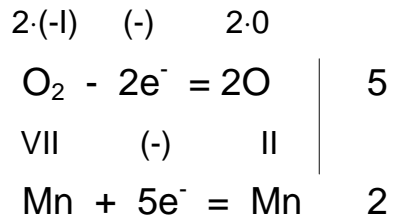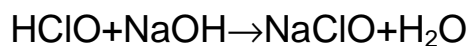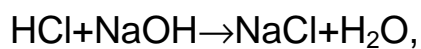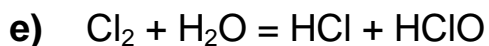
**6. a)** $C_{12}H_{22}O_{11}(t) + 12O_2(g) = 12CO_2(g) + 11H_2O(v)$   $\Delta H$(suc., combustion)

**b) $\Delta H$(suc.,comb.)** $= \Sigma\Delta H_f$ (final) - $\Sigma\Delta H_f$ (initial) =

   = 12 mol·(-393.5 kJ/mol) +11 mol·(-285.8 kJ/mol) -

   -1 mol·(-2222.0 kJ/mol)  - 12 mol·0 kJ/mol) = - **5643.8 kJ/mol**

**c)** $\Delta H$ [$H_2O(v) \rightarrow H_2O(g)$] = -241.8 kJ/mol -(-285.8 kJ/mol)  = 44.0 kJ/mol

The system receives energy; therefore the sign of $\Delta H$ is positive.

M(sucrose) = 342 g/mol

Energy produced by the oxidation of 1 gram of sucrose:

 +5643.8 kJ/mol $\cdot \dfrac{1 \text{ mol}}{342 \text{ g}}$ = 16.502 kJ/g $\approx$ 16.5 kJ/g

Energy needed to evaporate 1 litre of water:

 +44.0 kJ/mol · 100$\underline{0}$ cm$^{3.}$ 1.00 g/cm$^3$ · $\dfrac{1 \,\text{mol}}{18.0 \,\text{g}}$ = 2444 kJ $\approx$ 2440 kJ

**m(sucrose)** = 2444 kJ · $\dfrac{1 \,\text{g}}{16.5 \,\text{kJ}}$ = **148 g**


## FORM XI


**1. a)**  n(C) = 24$\underline{0}$ · 0.82 · $\dfrac{1}{12.01}$ = 16.38 $\approx$ 16.4

   n(O) = 24$\underline{0}$ · 0.069 · $\dfrac{1}{16.00}$ = 1.035

   n(H) = 24$\underline{0}$ · 0.11 · $\dfrac{1}{1.008}$= 26.19 $\approx$ 26.2

   **$C_{16.4}O_{1.035}H_{26.2}$**
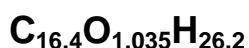
**b)** The following saturated compounds correspond to the unsaturated compound:

**i)** $C_{16}H_{32}O$ - ketone;

**ii)** $C_{16}H_{34}O$ - alcohol.

**c) i)**



5-methyl resorcine

**ii)**



5-ethyl resorcine

**iii)**
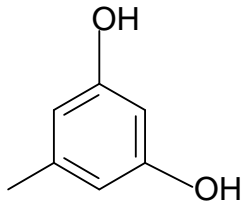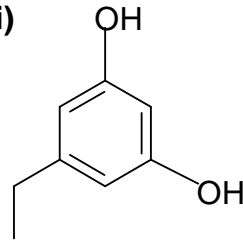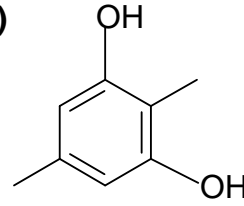


2,5-dimethyl resorcine

**d) i)**



decane

**ii)**



2-decanone

**iii)**



pentyl cyclohexane

**iv)**



1,7-oktadiene

**v)**



3-methyl phenole

**vi)**
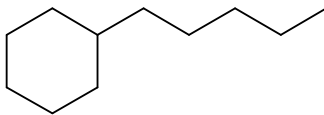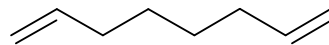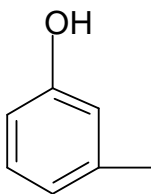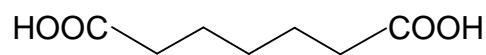


heptane dicarboxylic acid

**2. a) X** – C, carbon

   **Y** – O, oxygen

   **E** – CO, carbon monoxide

   **F** – CO$_2$, carbon dioxide

   **b) i)** If the number of oxygen atoms is two and the number of carbon atoms is three, then oxygen content is 47%.

$$n(C) = 2 \cdot 16 \cdot \frac{1}{47\%} \cdot 53\% \cdot \frac{1}{12} = 3$$

All other combinations don't satisfy the problem.

**ii)** $O=C=C=C=O$  (carbon has 4 bonds, oxygen – 2)

**c)** $M(-COOH) = 45$ g/mol
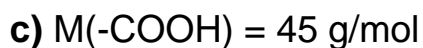
If **D** $\Leftrightarrow$ NaOH, then $m(\mathbf{D}) = 2.080$ g $\cdot \dfrac{1}{0.04 \text{ mol}} = 52$ g/mol

52 - 45 = 7

Doesn't fit because a fragment with this molar mass doesn't exist.

If **D** $\Leftrightarrow$ 2NaOH, then $M(\mathbf{D}) = \dfrac{1}{2} \cdot 2.080 \text{ g} \cdot \dfrac{1}{0.04 \text{ mol}} = 104$ g/mol

104 - 2·45 = 14

This molar mass corresponds to the fragment $-CH_2-$

$HOOCCH_2COOH$

**d)**



**A** $-$ süsihape

$H_2CO_3 = H_2O + CO_2$

**B** – HCOOH, formic acid

$HCOOH = H_2O + CO$

**C** – HOOCCOOH, oxalic acid

$(COOH)_2 = H_2O + CO + CO_2$

**D** – HOOCCH$_2$COOH, propane dicarboxylic acid

$HOOCCH_2COOH = 2H_2O + O=C=C=C=O$

**e) i)** $CO + NaOH = HCOONa$

**ii)** $2HCOONa = (COONa)_2 + H_2$

**iii)** $O=C=C=C=O + 2CH_3OH = CH_3OOCCH_2COOCH_3$

**3. a) i)** $2Ca_3(PO_4)_2 + 3SiO_2 + 10C = P_4 + 10CO + 3Ca_2SiO_4$
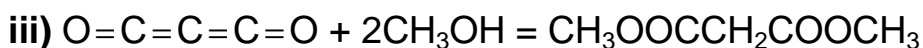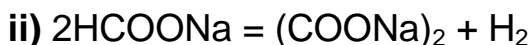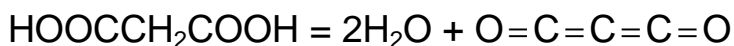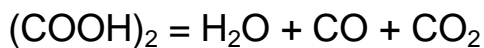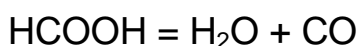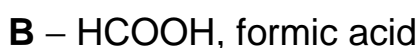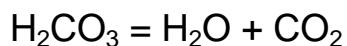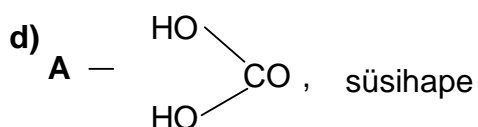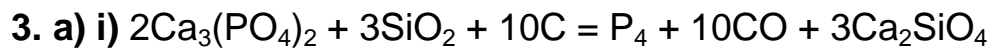
**ii) A** – $Ca_3(PO_4)_2$, calcium phosphate

**B** – $P_4$, white phosphorous

**C** – $P_n$, red phosphorous

**F** – $PH_3$, phosphine

**1)** Under water there is no oxygen which could oxidize phosphorous. Shining is caused by the reaction

$P + O_2 = PO_2$ (partial oxidation)
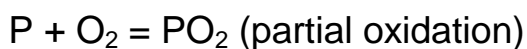
**2)** By a twofold dilution of 2 M muriatic acid 1 M solution is obtained

$pH = -\log[H^+] \Rightarrow -\log 1 \Rightarrow -\log 10^0 = 0$

**3)** $P_4 + 3NaOH + 3H_2O = 3NaH_2PO_2 + PH_3$
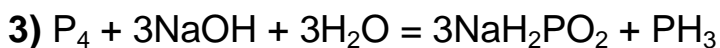
$P_2H_4$ is also formed in the reaction and its traces cause ignition of $PH_3$.

**4)** Phosphine doesn't have base properties. However it forms phosphonium salts with a very strong (acid neutralization occurs which causes pH increase).

$PH_3 + HClO_4 = PH_4ClO_4$

**5)** $Ca_3(PO_4)_2 + 2H_2SO_4 = Ca(H_2PO_4)_2 + 2CaSO_4$
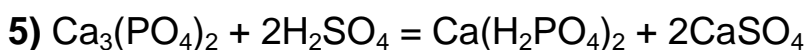
A soluble fertilizer – superphospate – is obtained.


**4. a) A** $-(CuOH)_2CO_3$, vaskhüdroksiidkarbonaat, sest lagunemisel eraldus ka vesi.

**B** – $CO_2$, süsinikdioksiid

**C** – $CuO$, vask(II)oksiid

**b) i)** $2CuSO_4 + 4NaHCO_3 = (CuOH)_2CO_3 + 2Na_2SO_4 + H_2O + 3CO_2$

**ii)** $(CuOH)_2CO_3 \xrightarrow{\,t^0t\,} 2CuO + CO_2 + H_2O$

**iii)** $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

**iv)** $Ca(OH)_2 + CO_2 + CO_2 = Ca(HCO_3)_2$

**v)** $3CuO + 2NH_3 = N_2 + 3Cu + 3H_2O$
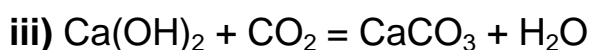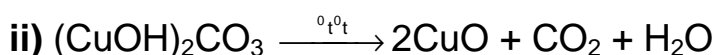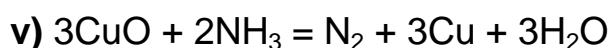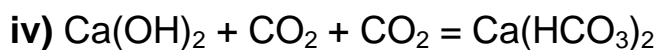
**c) i)** $0.13 = m \cdot \dfrac{160}{250} \cdot \dfrac{1}{27.8\,g}$

$m(CuSO_4 \cdot 5H_2O) = 0.13 \cdot 27.8\,g \cdot \dfrac{250}{160} = 5.646\,g \approx \mathbf{5.6\ g}$

**ii)** $m(H_2O) = 27.8\,g - 5.6\,g = \mathbf{22.2\ g}$

**d)** $V \cdot 1.22\ mol/dm^3 \qquad 27.8\,g \cdot 0.13$

$\qquad 4NaHCO_3 \quad \Leftrightarrow \quad 2CuSO_4$
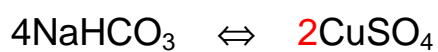
$\qquad\qquad\qquad 160\ g/mol$

$V(NaHCO_3) = \dfrac{4}{2} \cdot 27.8\,g \cdot 0.130 \cdot \dfrac{1\,mol}{160\,g} \cdot \dfrac{1\,dm^3}{1.22\,mol} \cdot 1000\,cm^3/dm^3 = \mathbf{37.0\ cm^3}$

**e)** $27.8\,g \cdot 13\% \qquad\qquad 2.4\,g$

$\qquad 2CuSO_4 \quad \Leftrightarrow \quad (CuOH)_2CO_3$
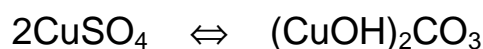
$\qquad 160\ g/mol \qquad\qquad 221\ g/mol$

$\%[yield,(CuOH)_2CO_3] = \dfrac{2}{1} \cdot 2.4\,g \cdot \dfrac{1\,mol}{221\,g} \cdot 160\,g/mol \cdot \dfrac{1}{27.8\,g} \cdot \dfrac{1}{0.13} \cdot 100 = \mathbf{96}$

**5. a) i)** $2Cr^{3+} + 3H_2O_2 + 10OH^- = 2CrO_4^{2-} + 8H_2O$ (charges $2 \cdot 3^+ + 10OH^- = 2 \cdot 2^-$)

$\qquad$ III $\qquad$ (-) $\qquad$ VI

$\qquad Cr^3 - 3e^- = CrO_4^{2-} \qquad\qquad \Big|\qquad 2$

$\qquad\ \ 2 \cdot (-I) \qquad (-) \qquad 2 \cdot (-II) \quad \Big|$

$\qquad H_2O_2 + 2e^- = 2O \qquad\qquad\ \ 3$

**ii)** $1CrO_4^{2-} + 3Fe^{2+} + 8H^+ = 3Fe^{3+} + Cr^{3+} + 4H_2O$ (charges $1 \cdot 2^- + 3 \cdot 2^+ + 8H^+ =$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad = 3 \cdot 3^+ + 1 \cdot 3^+$)

**iii)** $1MnO_4^- + 5Fe^{2+} + 8H^+ = 5Fe^{3+} + Mn^{2+} + 4H_2O$ (charges $1 \cdot 1^- + 5 \cdot 2^+ + 8H^+ =$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad + 5 \cdot 3^+ + 2^+$)
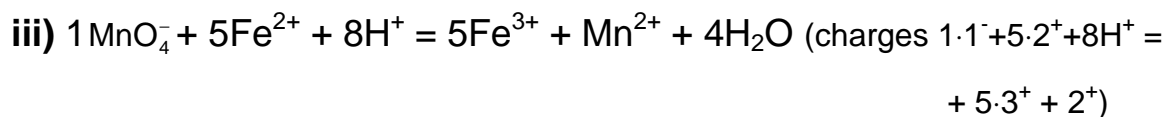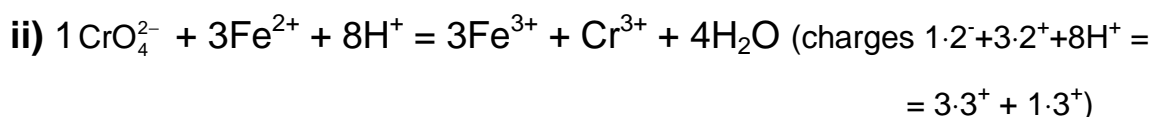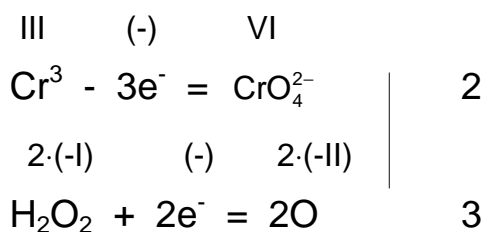
**b)** $n(Fe^{2+}) = 0.02400 \text{ l} \cdot 0.1500 \text{ mol/l} = 0.003600 \text{ mol}$

$n(MnO_4^-) = 0.03100 \text{ l} \cdot 0.0195 \text{ mol/l} = 0.0006045 \text{ mol}$

$n(Fe^{2+}, ox\ MnO_4^-) = \frac{5}{1} \cdot 0.0006045 \text{ mol} = 0.003023 \text{ mol}$

$n(Fe^{2+}, ox\ CrO_4^-) = 0.003600 - 0.003023 = 0.000577 \text{ mol}$

$\mathbf{m(Cr)} = 25 \cdot \frac{1}{3} \cdot 0.000577 \text{ mol} \cdot 52.0 \text{ g/mol} = \mathbf{0.250\ g}$

**c)** $Q = I \cdot t = 2.36 \text{ A} \cdot 575 \text{ sec} = 1357 \text{ A·s}$

$Q(Cr^{3+}) = \dfrac{0.250 \text{ g}}{5} \cdot \dfrac{1 \text{ mol}}{52.0 \text{ g}} \cdot 3 \cdot 96485 \text{ A·s/mol} = 278.3 \text{ A·s} \approx 278 \text{ A·s}$

$Q(Ag^+ + Cu^{2+}) = 1357 \text{ A·s} - 278 \text{ A·s} = 1079 \text{ A·s}$

If $Q(Cu^{2+}) = 1079 \text{ A·s} - Q(Ag^+)$

$2.50 \text{ g} - 0.250 \text{ g} = m(Ag^+) + m(Cu^{2+})$

$m(Ag^+) = 5 \cdot \mathbf{Q(Ag^+)} \cdot \dfrac{1 \text{ mol}}{96485 \text{ A·s}} \cdot 108 \text{ g/mol} = 0{,}00559\ \mathbf{Q(Ag^+)}/\text{A·s}$

$m(Cu^{2+}) = 5 \cdot [1079 \text{ A·s} - \mathbf{Q(Ag^+)}] \cdot \dfrac{1}{2} \cdot \dfrac{1 \text{ mol}}{96485 \text{ A·s}} \cdot 63.5 \text{ g/mol} =$

$= 0.001645 \text{ g/A·s}[1079 \text{ A·s} - \mathbf{Q(Ag^+)}] = 1.775 \text{ g} - 0.00165 \text{ g}\ \mathbf{Q(Ag^+)}/\text{A·s}$

$2.250 \text{ g} = 0.00559 \text{ g/A·s} \cdot \mathbf{Q(Ag^+)} + 1.775 \text{ g} - 0.00165 \text{ g/A·s} \cdot \mathbf{Q(Ag^+)}$

$0.475 = 0.00394\mathbf{Q(Ag^+)} \cdot 1/\text{A·s}$

$\mathbf{Q(Ag^+)} = 120.55 \text{ A·s} \approx 121 \text{ As}$

$Q(Cu^{2+}) = 1079 \text{ A·s} - 121 \text{ A·s} = 958 \text{ A·s}$

$\mathbf{m(Ag)} = m(Ag^+) = 5 \cdot 121 \text{ A·s} \cdot \dfrac{1 \text{ mol}}{96485 \text{ A·s}} \cdot 108 \text{ g/mol} = 0.677 \text{ g} \approx \mathbf{0.68\ g}$

$\mathbf{m(Cu)} = 2.250 - 0.677 = 1.573 \text{ g} \approx \mathbf{1.57\ g}$

**6. a)** $C_6H_5COOH \rightleftharpoons C_6H_5COO^- + H^+$
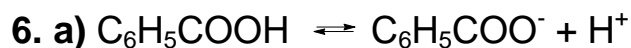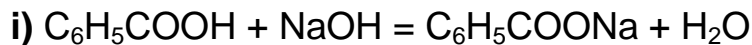
$$K_A = \frac{[C_6H_5COO^-][H^+]}{[C_6H_5COOH]}$$

If sodium benzoate is added then

$[C_6H_5COOH] = c_{acid}$   ja   $[C_6H_5COONa] = c_{salt}$

$[H^+] = K_A = \dfrac{c_{acid}}{c_{salt}}$

**b) A**

**i)** $C_6H_5COOH + NaOH = C_6H_5COONa + H_2O$

**ii)** $n(C_6H_5COOH) = 0.1\ dm^3 \cdot 0.05\ mol/dm^3 = 0.005\ mol$

$n(NaOH) = 0.03\ dm^3 \cdot 0.08\ mol/dm^3 = 0.0024\ mol$

$n(C_6H_5COOH,final) = 0.005\ mol - 0.0024\ mol = 0.0026\ mol$

$n(C_6H_5COONa,final) = \dfrac{1}{1} \cdot 0.0024\ mol = 0.0024\ mol$

$n(NaOH,final) = n(C_6H_5COONa,initial) = 0$

**iii)** $[H^+] = 6.5 \cdot 10^{-5}\ mol/dm^3 \cdot \dfrac{0.0026\ mol}{0.0024\ mol} = 7.04 \cdot 10^{-5}\ mol$

**pH** $= -log\ 7.04 \cdot 10^{-5} = 4.14 \approx$ **4.2**

**B**

**i)** $HCl + NH_3 \cdot H_2O = NH_4Cl + H_2O$

**ii)** $n(HCl) = 0.2\ dm^3 \cdot 0.4\ mol/dm^3 = 0.08\ mol$

$n(NH_3 \cdot H_2O) = 0.25\ dm^3 \cdot 0.5\ mol/dm^3 = 0.125\ mol$

$n(NH_4Cl,final) = \dfrac{1}{1} \cdot 0.08\ mol = 0.08\ mol$

$n(NH_3 \cdot H_2O,final) = 0.125\ mol - 0.08\ mol = 0.045\ mol$

$n(HCl,final) = n(NH_4Cl,initial) = 0$

**iii)** $[OH^-] = 1.79 \cdot 10^{-5} \cdot \dfrac{0.045\ mol}{0.08\ mol} = 1.01 \cdot 10^{-5}$

**pOH** $= -log\ 1.01 \cdot 10^{-5} = 5.0$

**pH** = $K_v$ - pOH = 14 - 5.0 = **9,0**

**C**

**i)** HCl + NaOH = NaCl + $H_2O$
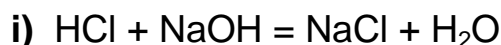
**ii)** n(HCl) = 0.01 $dm^3 \cdot$ 0.4 mol/$dm^3$ = 0.004 mol

n(NaOH) = 0.012 $dm^3 \cdot$ 0.4 mol/$dm^3$ = 0.0048 mol

n(NaCl,final) = $\frac{1}{1} \cdot$ 0.004 mol = 0.004 mol

n(NaOH,final) = 0.0048 mol − 0.004 mol = 0.0008 mol

n(HCl,final) = n(NaCl,initial) = 0

**iii)** The solution is of a strong base

$[OH^-]$ = $\frac{0.0008 \, \text{mol}}{0.022 \, \text{dm}^3}$ = 0.03636 mol/$dm^3$

pOH = -log 0.03636 = 1.44 ≈ 1.4

**pH** = 14 − 1.4 = **12.6**

## FORM XII

**1. a) X** – $SiO_2$, silicium dioxide, sand

**b) i)** n($CO_2$) = 45.1 g $\cdot \frac{1 \, \text{mol}}{44.0 \, \text{g}}$ = 1.025 mol

n(FeO)= 0.2 g $\cdot \frac{1 \, \text{mol}}{71.9 \, \text{g}}$ = 0.00278 mol ≈ 0.003 mol

n(CaO) = 48.1 g $\cdot \frac{1 \, \text{mol}}{56.1 \, \text{g}}$ = 0.857 mol

n(**Y**) = 1.025 mol − 0.003 mol − 0.857 mol = 0.165 mol

$$M(\mathbf{Y}) = 6.6\ g \cdot \frac{1}{0.165\ mol} = \textbf{40 g/mol}$$

The compound **Y** can't be $Me_2O$, because then $A_r(Me) = 12$. As the compound **Y** is MeO, then $A_r(Me) = 40 - 16 = 24$, which corresponds to magnesium.

**ii) Y** – MgO, magnesium oxide.

**c)** Acidic soils need treatment with shale ashes. CaO neutralizes acidity of soils.

**d)** CaO and $Al_2O_3$

**e)** $SO_2$ – from kerogen and clay-sand parts

$H_2O$ – from kerogen part

CaO – from carbonate part

**f) i)** $SO_2 + H_2O = H_2SO_3$

**ii)** $2H_2SO_3 + O_2 = 2H_2SO_4$

**iii)** $H_2SO_4 + CaO + H_2O = CaSO_4 \cdot 2H_2O$

**2. a)** The compound **A** should be $\mathbf{X}O_2$, because a five-atomic binary compound $\mathbf{X}Cl_4$ is formed from it.

$$M_r(\mathbf{A}) = 16 \cdot 2 \cdot \frac{1}{0.40} = 80$$

$$A_r(\mathbf{X}) = 80 - 32 = 48$$

**X** – Ti, titanium

**b) A** – $TiO_2$, titanium(IV) oxide

**B** – C, carbon

**C** – $Cl_2$, chlorine

**D** – $TiCl_4$, titanium(IV) chloride

**E** – CO, carbon oxide

**F** – $H_2$, hydrogen

**G** – $TiCl_3$, titanium(III) chloride

**H** – $Ti_2O_3 \cdot H_2O$, titanium(III) oxide monohydrate

**c) i)** $TiO_2 + 2C + 2Cl_2 = TiCl_4 + 2CO$

**ii)** $TiCl_4 + 2H_2O = TiO_2 + 4HCl$

**iii)** $TiCl_4 + 2Mg = Ti + 2MgCl_2$

**iv)** $2TiCl_4 + H_2 = 2TiCl_3 + 2HCl$

**v)** $2TiCl_3 + 6NaOH = Ti_2O_3 \cdot H_2O + 6NaCl + 2H_2O$

**vi)** $TiO_2 + CaO = CaTiO_3$ (calcium meta-titanate)

**vii)** $TiO_2 + 4NaOH = Na_4TiO_4 + 2H_2O$ (sodium ortho-titanate)


**3. a)** $n(H) \Leftrightarrow 2n(H_2O)$
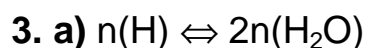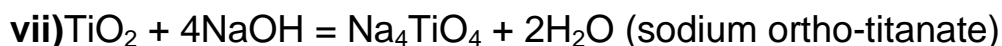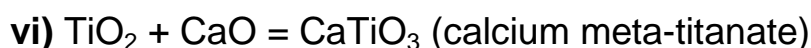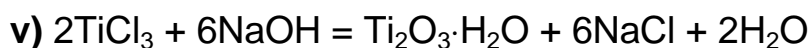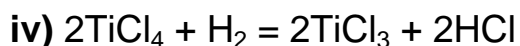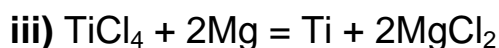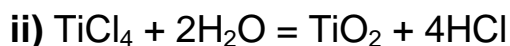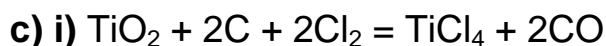
$n(H) = 2 \cdot 216.2 \text{ mg} \cdot \dfrac{1\,\text{mol}}{18.02\,\text{g}} = 24$ mmol

$n(C) \Leftrightarrow n(BaCO_3)$
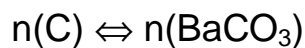
$n(C) = 1.973 \text{ g} \cdot \dfrac{1\,\text{mol}}{197.3\,\text{g}} = 10$ mmol

24 mmol $\cdot$ 1.008 g/mol + 10 mmol $\cdot$ 12.01 g/mol = 144.3 mg
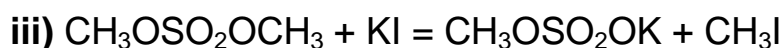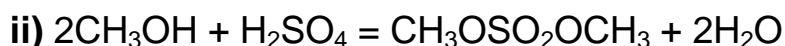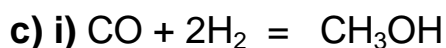
$n(O) = (176.3 \text{ mg} - 144.3 \text{ mg}) \cdot \dfrac{1\,\text{mol}}{16\,\text{g}} = 2$ mmol

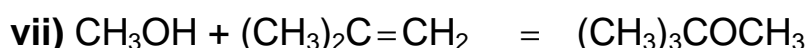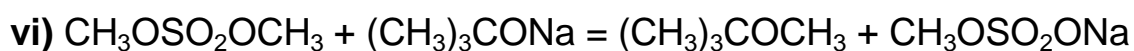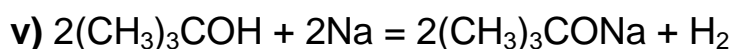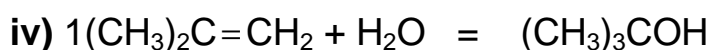C : H : O = 10 : 24 : 2    or   5 : 12 : 1, to which corresponds an empirical formula    **$C_5H_{12}O$**

**b) X** – $(CH_3)_3COCH_3$

**A** – $CH_3OH$

**B** – $(CH_3)_2C{=}CH_2$

**C** – $CH_3OSO_2OCH_3$

**D** – $CH_3I$

**E** – $(CH_3)_3COH$

**F** – $(CH_3)_3CONa$

cat

**c) i)** $CO + 2H_2 = CH_3OH$

**ii)** $2CH_3OH + H_2SO_4 = CH_3OSO_2OCH_3 + 2H_2O$

**iii)** $CH_3OSO_2OCH_3 + KI = CH_3OSO_2OK + CH_3I$

$H^+$

**iv)** $1(CH_3)_2C=CH_2 + H_2O = (CH_3)_3COH$

**v)** $2(CH_3)_3COH + 2Na = 2(CH_3)_3CONa + H_2$

**vi)** $CH_3OSO_2OCH_3 + (CH_3)_3CONa = (CH_3)_3COCH_3 + CH_3OSO_2ONa$

**vii)** $CH_3OH + (CH_3)_2C=CH_2 = (CH_3)_3COCH_3$
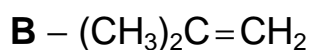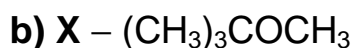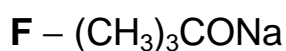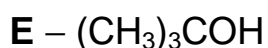
**4. a) M** $= \dfrac{1.71\,g}{0.025\,dm^3 \cdot 1.20\,mol/dm^3} =$ **57.0 g/mol**
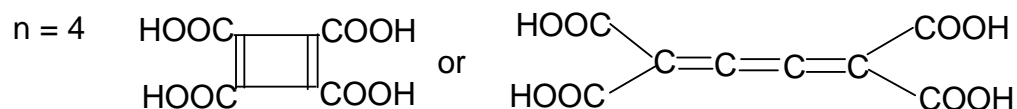
**b)** The formula of a monoprotic acid is R–COOH

$M(-COOH) = 45$ g/mol

$M(R) = 12$ g/mol

All carboxylic acids with the formula $(CCOOH)_n$ satisfy the titration data
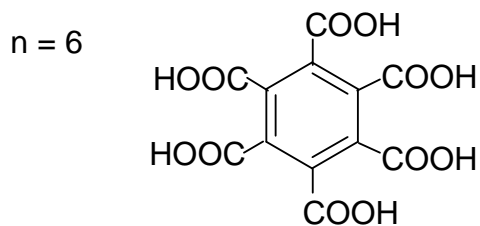
n = 1    such acid doesn't exist

n = 2    $HOOCC{\equiv}CCOOH$
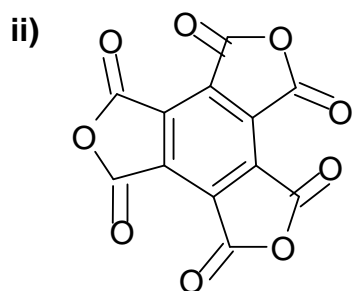
n = 3    isn't possible

n = 4     or 

n = 5    isn't possible

n = 6

**c)** An anhydride is formed by heating a carboxylic acid.

**d) i)** Benzene hexacarboxylic acid, as well as acids with n=4 and n=2;

**ii)**



$M_r(C_{12}O_9) = 144 + 144 = 288$

**5. a) i)** $2H_2O_2 = 2H_2O + O_2$

**ii)** $2KMnO_4 + 5H_2O_2 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 8H_2O + 5O_2$

**iii)**  $2KMnO_4 + 10FeSO_4 + 8H_2SO_4$  =  $K_2SO_4 + 2MnSO_4$ $+5Fe_2(SO_4)_3 + 8H_2O$

**b)** $k = \dfrac{1}{5\,min} \cdot \ln\dfrac{46.1}{37.1} = 0.04344\ min^{-1}$

$k = \dfrac{1}{10\,min} \cdot \ln\dfrac{46.1}{29.8} = 0.04363\ min^{-1}$

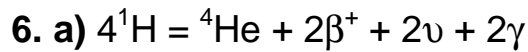$k = \dfrac{1}{20\,min} \cdot \ln\dfrac{46.1}{19.3} = 0.04354\ min^{-1}$

$k = \dfrac{1}{30\,min} \cdot \ln\dfrac{46.1}{12.5} = 0.04350\ min^{-1}$

k(average) = $0.0435\ min^{-1}$

**c)** $\tau = \dfrac{\ln 2}{0.0435\,min^{-1}} = 15.9\ min = 15\ min\ 54\ sec \approx$ **15 min 50 sec**

**d)** $\dfrac{c_o}{c_t} = e^{kt}$   $c_t = c_o \cdot e^{-k \cdot t}$

$n(KMnO_4) = 46.1 \text{ mmol} \cdot e^{-0.0435\,min^{-1} \cdot 50\,min} \approx \textbf{5.2 mmol}$

**6. a)** $4\,^1H = \,^4He + 2\beta^+ + 2\upsilon + 2\gamma$

**b)** $\Delta m = 4m(^1H) - m(^4He) - 2m(\beta^+) =$

$= 4 \cdot 1.00727 - 4.00273 - 2 \cdot 0.0005486 = \textbf{0.02525 amu}$

**c)** $\Delta m = \dfrac{5.0\,g}{1000\,g/kg} \cdot \dfrac{-0.02525\,am\ddot{u}}{4.02908\,am\ddot{u}} = $ -3.134·10$^{-5}$ kg

$\textbf{E} = $ -3,134·10$^{-5}$ · (3,0·10$^8$ m/s)$^2$ = **-2.82·10$^{12}$ J**

**d)** $H_2 + 1/2\,O_2 = H_2O$
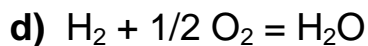
Energy released in the reaction $\dfrac{-286\,kJ/mol}{2.0\,g/mol} \cdot 1000\,J/kJ \cdot 5.0\,g = $ -7.1·10$^5$ J

**Ratio**$= \dfrac{-2.82 \cdot 10^{12}}{-7.1 \cdot 10^5} = $ **3.9·10$^6$**