52th CHEMISTRY OLYMPIAD
Final National Competition

2005

ESTONIA

Problems

Form X

1. To make an analysis, Andres has received samples of three solid metals, two of which were outwardly very similar and the third one was more tarnished than others. Andres found out that reacting the metals with a diluted solution of HCl, with cold concentrated HNO_3 and a concentrated solution of NaOH may help to identify the metals.

Reagent	Metal I	Metal II	Metal III
HCl	–	+	+
HNO_3	+	–	+
NaOH	–	+	+

a) What chemical elements are metals I, II and III?

b) Write the equations for the appropriate reactions, base your answer on the data, which is contained in the table above. (6 equations)

c) Substantiate (give the formulas where possible), why metals do not corrode under standard conditions.

2. Germans proposed to use element **A** as a fuel. Element **A** is used in the process of energy production. An exothermic reaction in the presence of catalysis (CuO) happens between element **A** and elementary substance **B**. As a result, the new substance **C** is formed. It doesn't pollute the environment because in the reaction of **C** and substance **E**, only ammonia and substance **D** are formed. Ammonia may be used to obtain salts that are used as fertilizers. Binary compound **D** contains 53% of oxygen and doesn't react with water.

a) Estimate **i)** the formula of substance **D** and write its name. **ii)** Write down the formulas and give names for **A**, **B**, **C**, **E**.

b) Write down the equations **i) A** + **B** →; **ii) C** + **E** →; **iii)** NH_3 → fertilizer.

c) Why this method of energy production is not used practically? What is the main reason?

3. It is impossible to prepare a solution with exact molar concentration, using exact mass of NaOH charge. NaOH is very hygroscopic. It can also react with CO_2 contained in the air. To prepare 1 litre ~0.1 M of NaOH solution, a laboratory assistant took a 1.00-litre volumetric flask, filled it with 5.2 cm^3 of saturated solution of NaOH and diluted it with water up to the mark. To determine

the concentration of the obtained solution, the laboratory assistant used a solution of oxalic acid of exact concentration.

a) Draw the graphic formula of oxalic acid.

b) Write the equation for neutralization of NaOH with oxalic acid.

c) Calculate i) Molar mass of oxalic acid dehydrate. ii) Mass of crystalline hydrate that is necessary for preparation of exactly 100 ml 0.5000 M solution.

d) Calculate the molar concentration of the obtained NaOH solution, if 10.20 cm^3 of NaOH solution is required to titrate 10.00 ml of prepared solution.

e) Calculate the percentage of NaOH in the saturated solution, if density of the given one is 1.54 g/cm^3.

4. On the 15th April 1912 in the Atlantic Ocean the famous ship Titanic sank. Many factors caused problems including shortness of steel constructions in the ship. This could have been due to excessive content of nonmetals **X** and **Y**. The first one causes the shortness of steel at high temperature and the second at low temperature. The feedstock of steelmaking is cast iron, of which the basic component is elementary substance **A**. Cast iron also contains some touches of nonmetals **Y**, **Q**, **Z**, as well as binary salt **R**, which is formed by the main component and nonmetal **X**. Content of nonmetal **X** in salt **R** equals 36.5% Elements **Q** and **Z** belong to one group of the periodic table. Elements **X**, **Y** and **Z** belong to one period.

During the steelmaking process part of elementary substance **A** is oxidized in presence of oxygen giving compound **B**. Then the following reactions take place:

B + **Y** = **A** + **D** (oxide **D** with a high molar mass; element **Y** contained in **D** has the maximal oxidation number; aqueous solution **D** is acidic).

B + **Q** = **A** + **E** (oxide **E** – toxic gas, in which **Q** is not completely oxidized).

B + **Z** = **A** + **G** (element **Z** in oxide **G** has the maximal oxidation number. When it is put into water the medium is neutral).

To get rid of salt **R** the limestone is used. At first limestone decomposes: limestone = **J** + **L** (**L** is a gas that is also obtained by the oxidation of gas **E**). Then a reaction **J** + **E** = **B** + **M** takes place (**M** – binary salt, which contains 44.4% of element **X**).

a) Write i) the formula of elementary substance **A**, ii) the equation for limestone decomposition; iii) the equation in which compound **B** is obtained.

b) i) Which metal forms salts **R** and **M**? Calculate the atomic mass of element **X** assuming the percentage in salts ii) **R** and iii) **M**.

c) Determine substances **Y**, **Q**, **Z**, **X**, **R**, **B**, **D**, **E**, **G**, **J**, **L**, **M** (formula and name).

d) Write down the equations i) **B** + **Y** →; ii) **B** + **Q** →; iii) **B** + **Z** →; iv) **J** + **R** →.

5. There are three isomers of crystalline hydrate **R** – metal **X** salt: **A** (blue-violet), **B** (dark green), **C** (light green). Coordination number of **X** is six; oxidation number of **X** in isomers **A**, **B**, **C** equals +3. In crystalline hydrate **R** contains: 19.5% of element **X**, 40.0% of element **Y**, 36.0 of oxygen and 4.5% of hydrogen (hydrogen belongs to water molecules only). The exact composition of isomers (inner and outer coordination sphere) may be found by the reaction between fresh solution of given isomer with silver nitrate (compound **Q**). A white

binary precipitate **Z** is obtained, which quantity may help determinate the quantity of element **Y**, containing in the isomer. In the reaction of **Q** with **A**, **B** and **C**: all, 2/3 and 1/3 of **Y** atoms respectively precipitate in form of salt **Z**.

a) Write the equation using symbols of ions and formulas of compounds: $\mathbf{Y}^{n-}$ + **Q** → **Z**↓ + ... Write down the formulas of **Y**, **Q**, **Z** and name them.

b) Calculate the quantity of O and H (in moles) that contain in 100 g of crystalline hydrate.

c) Determine the brutto-formula of crystalline hydrate and calculate the atomic mass of element **X**. Write the symbol and name the element **X**.

d) Write the exact formulas of isomers **A**, **B** and **C** of crystalline hydrate **R**.

6. In combustion of all organic compounds **A** and **B** are formed. **B** consists of elements that belong to the same period. Some living cells (using light for the energy) can make the reaction **A** + **B** → **Q** + **Z** happen. Molar mass of compound **Q** is 180 and it contains 40.0% of carbon, 6.7% of hydrogen and 53.3% of oxygen. **Z** is elementary gaseous substance, contained in compounds **A** and **B**. Gas **C** is formed by the explosion of gases **D** and **E** initiated by flash of light. Gas **D** is formed during the water electrolysis. Gas **E** is a yellow-green, heavy and poisonous.

a) Write the formulas of substances **A**, **B**, **Z**, **C**, **D** and **E** and give their names.

b) Calculate the brutto-formula of compound **Q** and give its name.

c) Write the equation **A** + **B** = **Q** + **Z**.

There are $1.00 \cdot 10^{25}$ of molecules of substance **A** in the vessel. $1.5 \cdot 10^{21}$ molecules of gas **C** were absorbed by substance **A**.

d) Determine the molar concentration of the obtained solution. Suppose that the volume of solution equals the volume of substance **A**; $\rho(\mathbf{A})$ = 1.00 g/cm^3.

Form XI

1. A caretaker wants to know the mass of sodium chloride that is needed to melt ice on the pavement (0.92 g/cm^3) near the house. The length of the pavement is 55 m and width is 1.5 m. Average thickness of ice is 5.0 cm. Temperature equals -3.0. $\Delta T = mK_{cr}$, where K_{cr} – cryoscopic constant of water; m – molal concentration of particles (in this case these particles are ions), mole/kg.

a) Calculate how many kilograms of sodium chloride does the caretaker need to clean the pavement?

b) Determine the minimal temperature, which can be reached using NaCl, if solubility of NaCl equals 30.0 g.

2. A, **B**, **C**, and **D** substances are binary nitric compounds that contain elements from the same group of the periodic system.

Compound **A** – oily volatile pale-yellow liquid that was firstly synthesized by Dulong in 1811. He passed Cl_2 through an acidulous solution of NH_4Cl. Substance **A** is unstable and decomposes after every blow. Due to lack of knowledge Dulong lost three fingers and an eye. During water disinfection (with chlorine), a compound **A** is formed (the quantity is not dangerous). Carbamide, which is usually contained in sweat and urine, reacts with chlorine water, forming compound **A**, gas **E** and a strong mineral binary acid **F**. Acid **F** was also obtained in Dulong's experiment. Substance **A** may be sanitized by the electrolysis of aqueous solution of NH_4Cl. As a result by-products hydrogen and gas **G** are formed. In the presence of gas **G** phenolphthalein-paper turns red.

Compound **B** was synthesized in 1975 at temperature -78 using the following compounds: $(Me_3Si)_2NBr$ and $ClBr$. The second product of the given reaction is trimethylsilane chloride.

When crystalline iodine reacts with ammonia hydrate, ammonium iodide, water and a complex of compound **C** are formed. In the molecule (446 g/mole) of **C** complex, ammonia molecules are its ligands. Compound **C** may be obtained in pure form by reaction between boron nitride and IF, where a boron fluoride is also formed. After the blow of **B** and **C** compounds, exothermal decomposition into elementary substances takes place.

Relatively stable substance **D** may be obtained by the reaction of fluoride with ammonia in the presence of Cu-catalysis. A hydrogen fluoride is also formed in the reaction.

a) Write down **i)** the formulas of compounds **A**–**G** and give their names, **ii)** the formula of trimethylsilane chloride, **iii)** the formula of the **C** complex.

b) Write the equations: **i)** $\rightarrow$ **A**; **ii)** $(NH_2)_2CO + Cl_2 + H_2O$; **iii)** $NH_4Cl \xrightarrow{\text{electrolysis}}$; **iv)** $\rightarrow$ **B**; **v)** $I_2 \rightarrow$ **C** complex; **vi)** $IF \rightarrow$ **C**; **vii)** **C** $\xrightarrow{\text{explosion}}$; **viii)** $\rightarrow$ **D**.

3. In the reaction of NaCN with 2-bromobutane, compound **A** and salt **B** are formed. Reduction of **A** with an excess of hydrogen on the surface of Ni gives compound **C**, which belongs to a well-known class of organic compounds **X**. By the partial acidic hydrolysis of compound **A**, crystals of **D** are obtained. **D** may be reduced in the presence of water and $LiAlH_4$, giving compound **C**. One of the laboratory methods describes how compound **D** may be obtained in the reaction of 2-methylbutanoyl chloride with ammonia.

When mixture of nitric and sulphuric acids reacts with benzene, a monoderivative **E** is formed. Compound **F**, which belongs to the class of organic compounds **X**, is obtained by the reduction of this monoderivative with Sn and HCl.

a) Write the name of class **X**.

b) Draw graphic formulas of substances **A**, **B**, **C**, **D** and **F**, write their names.

c) Write down the equations: **i)** 2-bromobutane + NaCN →; **ii)** 2-methylbutanoyl chloride + NH_3→; **iii)** benzene → **E**.

4. Al is the most abundant metal in the earth's crust. It is obtained from mineral – bauxite, of which formula is $AlO_x(OH)_{3-2x}$, where $0 < x < 1$. Pure Al_2O_3 is obtained from bauxite (it contains admixtures SiO_2 and Fe_2O_3), assuming its amphoteric properties. Metallic Al is formed in electrolysis of fused electrolyte (940° C) on the graphite electrodes. Al_2O_3 dissolves in the melt of Na_3AlO_3, CaF_2 and AlF_3 and dissociates: $Al_2O_3 \rightleftarrows Al^{3+} + AlO_3^-$. During the electrolysis anode burn in the current of produced oxygen and anion yields Al_2O_3, which dissociate giving Al^{3+} and AlO_3^-.

a) Write the equations **i)** Al_2O_3 + NaOH → complex; **ii)** complex → base; **iii)** base → Al_2O_3.

b) Write the equations for **i)** cathode **ii)** anode and **iii)** summary electrolysis reactions.

c) Calculate the current in the electrolyser if 80 kg of Al was obtained during a week of production, and current yield equals 95%.

d) Calculate the electricity charges, which are paid for production of one tone of Al, if potential difference across the electrolyser is 6.00 V and cost of 1 kW·h – exactly one crown.

5. Two experiments were carried to learn more about the solubility of $KClO_4$.

1. 1.30 g of $KClO_4$ were diluted in 50.0 mL of distilled water at 4° C. 0.59 g didn't dissolve. The volume of the solution increase by 0.3 cm^3.

2. 1.30 g of $KClO_4$ were diluted in 70.0 g solution of perchloric acid at 4° C. Density of obtained solution equalled 1.01 g/cm^3.

a) Calculate $S(KClO_4)$ in the distilled water at 4° C.

b) Calculate $K_{sp}(KClO_4)$ at 4° C.

c) Calculate for the second experiment in the solution of $HClO_4$ **i)** molar concentration $c(ClO_4^-)$ and **ii)** $S'(KClO_4)$.

d) Calculate the solubility of potassium perchlorate in 100 g of $HClO_4$ solution (second experiment).

e) Calculate the mass of undiluted salt in the second experiment.

6. Metals **A**, **B** and **C** belong to the fourth period. Metals **D** and **E** are in the same group, one under another. Aqueous solutions that contain ions **D** and **E** are colourless. Aqueous solution of **A**-ions is blue; **B**-ions is greenish. A blue precipitate that is formed in the reaction of NaOH with **A** decomposes on heating into water and black oxide. On heating the white precipitate, that is formed

in the reaction of NaOH with D, water is lost giving a yellow oxide (465.96 g/mol). The atomic numbers of metals **A** and **B** differ by 1; **B** and **C** differ by 3.

a) **i)** Write the equation for the reaction, where an oxide from metal hydroxide **D** is obtained. **ii)** Calculate atomic mass of **D**. **iii)** Write down its symbol and name.

b) Write symbols of metals **A**, **B**, **C** and **E** and give their names.

c) Write the equations: A^{2+}; B^{2+}; C^{2+} + Cl^- + H_2O. A^{2+} forms tetraaqua complex, B^{2+} and C^{2+} – heksaaqua complexes.

Form XII

1. Bunsen discovered the very active metal **A** in 1861 by its two dark-red spectrum lines. Metal **A** was named after these lines. When metal **A** is burned, three-atomic compound **B** is formed, which reacts with metal **A** forming three-atomic compound **C**. When **C** is being reduced by hydrogen, compound **I** and compound **D**, which completely ionizes in water, are formed. When compound **I** reacts with water, compound **D** and hydrogen are obtained. During the reaction of **B** not only with water, but also with sulphur acid, an elementary substance **X** and compound **Q** are formed. Elementary substance **X** is obtained during the decomposition of **Q**. When **B** reacts with water, compound **D** is formed, with H_2SO_4 – compound **E**. In the reaction of **E** with barium hydroxide, compound **D** is obtained. In the reaction of **D** with carbon dioxide, an acidic salt **F** is formed. It reacts with ammonium carbonate forming neutral salt **F**. In the reaction of salt **F** with HI, a binary compound **H**, which contains 40.25% of metal **A**, is formed.

a) Identify metal **A** using calculations; write its symbol and name.

b) Write formulas and name the substances **B**, **C**, **D**, **E**, **F**, **G**, **H**, **I**, **X** and **Q**.

c) Write equations: **i)** → **B**; **ii)** → **C**; **iii) B** → **D**; **iv) I** → **D**; **v) B** + H_2O →; **vi) B** + H_2SO_4 →; **vii) Q** → **X**; **viii) E** → **D**; **ix) D** → **F**; **x) D** → **G**; **xi) G** → **H**.

2. There is an ampoule with 10.00 grams of white samarium oxide (Sm_2O_3). The activity of sample is 89.2 Bq/g (Bq – becquerel, decay per second). The main source of radioactivity is samarium isotope ^{147}Sm ($t_{1/2} = 1.06 \cdot 10^{11}$ years, there are 365.25 days in a year).

Assume that there were no radioactive nuclides at the moment, when the sample was firstly obtained.

a) Calculate the time required for the amount of radioactive atoms to decay to 10% of initial number.

b) Calculate the percentage of the initial quantity of the radioactive substance temaining after five years.

c) Use the answer of b) to calculate percent of ^{147}Sm in samarium.

d) Calculate the amount of atoms of ^{147}Sm decayed in 10.00 grams of samarium oxide after 5 years.

3. Optically active α-aminoacid **X** ($C_4H_8NO_2Cl$) has two chiral centres. In the reaction of compound **X** with NaOH solution, a new compound **Y** is formed, which contains neither chlorine, nor sodium.

IR spectrum of Y shows that it contains intermolecular hydrogen bond.

When **X** reacts with excess of NaOH, a compound **Z** is obtained ($C_4H_8NO_3Na$). We'll name the S,S-isomer of **X** – **SX**. Reduction of **SX** by $LiAlH_4$ gives **M**. In the substitution reaction of M with PCl_5 compound **N** is obtained.

a) Draw Fisher's projections for compounds **X**, **Y** and **Z**. *Designate with asterisk (*) chiral atoms.*

b) Draw the graphic formula of **Y**, point at the intermolecular hydrogen bond.

**c)** Write the reaction scheme **SX** → **M** → **N** using stereochemical formulas.

4. The best way to remove rust from steel surfaces is to use orthophosphoric acid solution. Elimination of oxidative coating occurs faster, than the reaction between metal and orthophosphoric acid. Ions of iron (III) precipitate as in the form of iron hydroxide as of iron phosphate. Dissociation constants are: $K_1 = 7.52 \cdot 10^{-3}$, $K_2 = 6.31 \cdot 10^{-8}$, $K_3 = 1.26 \cdot 10^{-12}$, $K_{sp}(Fe(OH)_3) = 4.0 \cdot 10^{-38}$, $K_{sp}(FePO_4) = 1.3 \cdot 10^{-22}$. The fraction, $\alpha(PO_4^{3-})$, of dissociated H_3PO_4 in a solution of 0.100 M H_3PO_4 equals $3.3 \cdot 10^{-17}$.

a) Write ion equations: **i)** $Fe_2O_3 + H^+ \rightarrow$; **ii)** $Fe + H^+ \rightarrow$; **iii)** $Fe^{3+} + PO_4^{3-} \rightarrow$; **iv)** $Fe^{3+} + OH^- \rightarrow$.

b) Calculate pH **i)** of 0.100 M solution of H_3PO_4 and **ii)** of $1 \cdot 10^{-8}$ M H_3PO_4.

c) Calculate $[Fe^{3+}]$, if the precipitate of $FePO_4$ is in equilibrium with **i)** pure water and **ii)** with 0.100 M H_3PO_4 solution.

5. Medications produced on the basis of element **A** have been used by people for thousands of years. One of the first medications was a rich-red mineral that was a binary compound of **A** and **B** elements. Atomic number of **B** differs from **A** by 5. Element **A** is obtained at heating of compound **AB** in air current at 360° C, a colourless gas **C** with strong smell is evolved. During the reduction of **B** with sodium, a compound **D** is formed. In the reaction of compound **D** with gas **C**, a compound **E** and also element **D** – elementary substance – are obtained. **E** crystallizes as a pentahydrate; it is used in iodimetry-titretion and as an antidote for cyanide poisoning. When soluble salts of **A** react with alkali, **F** and **G** oxides are obtained; $M(\mathbf{F}) = 0.519 \cdot M(\mathbf{G})$.

a) Write formulas (symbols) and names for the substances **A–G**.

b) Write the equations: **i)** $\mathbf{AB} + O_2 \rightarrow \mathbf{A} + \mathbf{C}$; **ii)** $\mathbf{B} + Na \rightarrow \mathbf{D}$; **iii)** $\mathbf{D} + \mathbf{C} \rightarrow \mathbf{E} + \mathbf{B}$; **iv)** $\mathbf{E} + I_2 \rightarrow NaI + ...$; **v)** $KCN + \mathbf{E} \rightarrow KSCN + ...$; **vi)** $\mathbf{A}(NO_3)_n + NaOH \rightarrow \mathbf{F} + ...$; **vii)** $\mathbf{A}(NO_3)_m + NaOH \rightarrow \mathbf{G}$.

c) Calculate the molar masses of oxides **G** and **F**.

6. 4,5-dihydroxy-1-phenylhexan-3-one synthesis scheme:
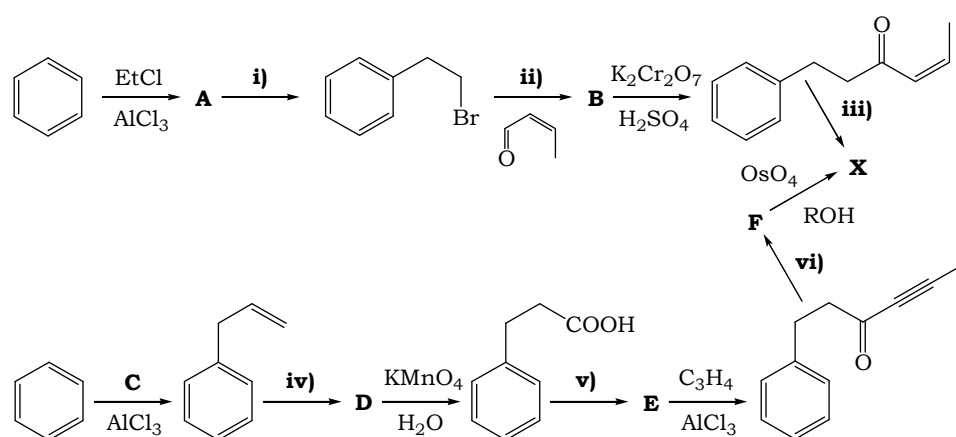
Compounds **C** and **E** contain chlorine. Reactions go with the following reagents: Mg; OsO_4/ROH; $SOCl_2$; $H_2/Pd(BaSO_4)$; $Br_2/h\nu$; 1. B_2H_6, 2. $H_2O_2/NaOH$.

a) Draw structural formulas of **A–F**.

b) Determine the reagents **i)–vi)**.

c) Draw structural formula of **X**.

Solutions

Form X

1.

a) I − Ag, silver; II − Al, aluminium, III − Zn, zink.

b) $Ag + 2HNO_3 = AgNO_3 + NO_2 + H_2O$

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

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

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

$Zn + 4HNO_3 = Zn(NO_3)_2 + 2NO_2 + 2H2O$

$Zn + 2NaOH + 2H_2O = Na_2[Zn(OH)_4] + H_2\uparrow$
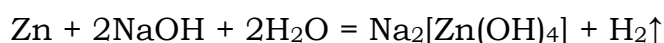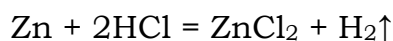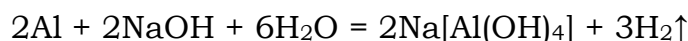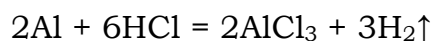
a) Silver is a passive metal. Al and Zn are covered with dense protective layer of Al_2O_3 and ZnO.

2.

a) i) Element **D** is an oxide of element **A**: $M(A) = \dfrac{47}{53} \cdot 16n$, $n = 2$, $M(A) = 28$,

D – SiO_2, silicon(IV) oxide.

ii) A – Si, silicon;

B – N_2, nitrogen;

C – Si_3N_4, silicon nitride;

E – H_2O, water.

b) i) $3Si + 2N_2 \xrightarrow{\text{CuO}} Si_3N_4$

ii) $Si_3N_4 + 6H_2O = 3SiO_2 + 4NH_3$

iii) $2NH_3 + H_2SO_4 = (NH_4)_2SO_4$
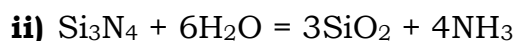
c) The production of silicon is very complicated.

3.

a)
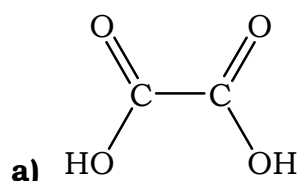
b) $(COOH)_2 + 2NaOH = (COONa)_2 + 2H_2O$

c) i) $M[(COOH)2\cdot2H_2O] = (12.01\cdot12 + 16.00\cdot6 + 1.008\cdot6) = 126.07$ g/mol;

ii) $m = 0.100$ dm³·0.05000 M·126.07 g/mol $= 0.63035$ g $\approx 630{,}4$ mg.

d) $c(NaOH) = \dfrac{2}{1} \cdot 0.05000 \text{ M} \cdot \dfrac{10.00 \text{ cm}^3}{10.20 \text{ cm}^3} = 0.09804 \text{ M}$.

e) $\%(NaOH) = \dfrac{0.09804 \text{ M} \cdot 1.00 \text{ dm}^3 \cdot 40.0 \text{ g/mol}}{5.2 \text{ cm}^3 \cdot 1.54 \text{ g/cm}^3} \cdot 100 = 49\%$.

4.

a) i) **A** – Fe, iron;

ii) $CaCO_3 = CaO + CO_2\uparrow$

iii) $2Fe + O_2 = 2FeO$
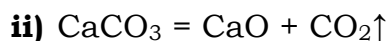
b) i) **R** – Fe salt; **M** – Ca salt

ii) $M(\mathbf{X}) = 55.8 \cdot 36.5 / 63.5 = 32.1$

iii) $M(\mathbf{X}) = 40.1 \cdot 44.4 / 55.6 = 32.0$

c) **Y** – P, phosphorus   **D** – P_4O_{10}, tetraphosphorus dekaoxide

    Q – C, carbon   **E** – CO, carbon monoxide

    Z – Si, silicon   **G** – SiO_2, silicon dioxide

    X – S, sulphur   **J** – CaO, calcium oxide

    R – FeS, iron(II) sulfide   **L** – CO_2, carbon dioxide

    B – FeO, iron(II) oxide   **M** – CaS, calcium sulfide

d) i) $10FeO + 4P = 10Fe + P_4O_{10}$

    ii) $FeO + C = Fe + CO$

    iii) $2FeO + Si = 2Fe + SiO_2$

    iv) $CaO + FeS = FeO + CaS$
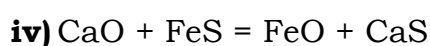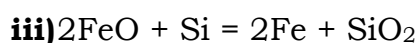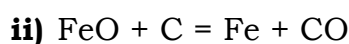
5.

a) $Cl^- + AgNO_3 \rightarrow AgCl + NO_3^-$;

    Y – Cl, chlorine; **Q** – $AgNO_3$, silver nitrate; **Z** – AgCl, silver chloride.

b) $n(O_2) = 0.36 \cdot \dfrac{100\ \text{g}}{16.0\ \text{g/mol}} = 2.25$ mol;

    $n(H_2) = 0.045 \cdot \dfrac{100\ \text{g}}{1.0\ \text{g/mol}} = 4.5$ mol;

c) Hydrogen belongs only to water molecules, $n(H_2O) = \frac{1}{2}n(H) = 2.25$ mol. We know that $n(H_2O) = n(O)$, it means that there is no oxygen in anion. Anion is formed by element **Y** (Cl^-). **X** – Cr, chromium, hydrate – $CrCl_3\cdot6H_2O$:

$$n(\mathbf{X}) = \frac{n(Cl)}{3} = \frac{1}{3}\cdot 0.40 \cdot \frac{100\,\text{g}}{35.5\ \text{g/mol}} = 0.3756\ \text{mol}$$

$$M(X) = \frac{0.195 \cdot 100\ \text{g}}{0.3756\ \text{mol}} = 51.9\ \text{g/mol}$$

d) **A** – $[Cr(H_2O)_6]Cl_3$; **B** – $[Cr(H_2O)_5Cl]Cl_2\cdot H_2O$; **C** – $[Cr(H_2O)_4Cl_2]Cl\cdot 2H_2O$.

6.

a) **A** – H_2O, water   **C** – HCl, hydrogen chloride

    B – CO_2, carbon dioxide   **D** – H_2, hydrogen

    Z – O_2, oxygen   **E** – Cl_2, chlorine

b) **Q** – $C_6H_{12}O_6$, glucose

$$n(\text{C}) = \frac{180 \text{ g}}{12 \text{ g/mol}} \cdot 0.40 = 6 \text{ mol}$$

$$n(H) = \frac{180 \text{ g}}{1.0 \text{ g/mol}} \cdot 0.067 = 12 \text{ mol}$$

$$n(\text{C}) = \frac{180 \text{ g}}{16 \text{ g/mol}} \cdot 0.533 = 6 \text{ mol}$$

c) $6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$
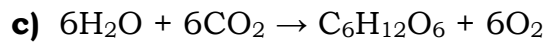
d) $V(H_2O) = \dfrac{1.00 \cdot 10^{25} \cdot 18.0 \text{ g} \cdot \text{mol}^{-1}}{6.02 \cdot 10^{23} \text{ mol}^{-1} \cdot 1000 \text{ g} \cdot \text{cm}^{-3}} = 0.299 \text{ dm}^3$

$$c(\text{HCl}) = \frac{1.5 \cdot 10^{21}}{6.02 \cdot 10^{23} \text{ mol}^{-1} \cdot 0.299 \text{ dm}^3} = 0.0083 \text{ M}$$

Form XI

1.

a) $m(\text{H}_2\text{O}) = 55 \text{ m} \cdot 1.5 \text{ m} \cdot 0.05 \text{ m} \cdot 920 \text{ kg/m}^3 = 3795 \text{ kg}$

$m(\text{ions}) = \dfrac{3.0 \text{ K}}{1.86 \text{ K} \cdot \text{kg}} = 1.613 \text{ mol/kg}$

$m(\text{NaCl}) = 1.613 \text{ mol/kg} \cdot \dfrac{1}{2} \cdot \dfrac{3765 \text{ kg}}{1000 \text{ kg/g}} \cdot 58.44 \text{ g/mol} = 180 \text{ kg}$

b) $t = 0^\circ \text{ C} - 2 \cdot \dfrac{300 \text{ g}}{\text{kg}} \cdot \dfrac{1.86 \text{ K} \cdot \text{kg/mol}}{58.44 \text{ g/mol}} = -19.1^\circ \text{ C}$

2.

a) i) **A** – NCl$_3$, nitrogen chloride;

B – NBr$_3$, nitrogen bromide;

C – NI$_3$, nitrogen iodide;

D – NF$_3$, nitrogen fluoride;

E – CO$_2$, carbon dioxide;

F – HCl, hydrogen chloride;

G – NH$_3$, ammonia

ii) Me$_3$SiCl

iii) $n(NH_3) = \dfrac{446 - (14 + 3 \cdot 127)}{17} = 3$

b) i) NH$_4$Cl + 3Cl$_2$ = NCl$_3$ + 4HCl

ii) (NH$_2$)$_2$CO + 6Cl$_2$ + H$_2$O = 2NCl$_3$ + CO$_2$ + 6HCl

iii) 3NH$_4$Cl = NCl$_3$ + 3H$_2$ + 2NH$_3$

iv) (Me$_3$Si)$_2$NBr + 2ClBr = NBr$_3$ + 2Me$_3$SiCl

v) 3I$_2$ + 7NH$_3$·H$_2$O = NI$_3$·(NH$_3$)$_3$ + 3NH$_4$I + 7H$_2$O

vi) BN + 3IF = NI$_3$ + BF$_3$

vii) 2NI$_3$ = N$_2$ + 3I$_2$

viii) 3F$_2$ + NH$_3$ = NF$_3$ + 3HF

3.

a) amides

A

2-methylbutanenitrile

D

2-methylbutanamide

E

nitrobenzene

C

2-methylbutan-1-amine

B - NaBr

sodium bromide

F

aniline

b)

4.

a) i) $Al_2O_3 + 6NaOH + 3H_2O \rightarrow 2Na_3[Al(OH)_6]$

   ii) $Na_3[Al(OH)_6] + 3HCl \rightarrow Al(OH)_3\downarrow + 3NaCl + 3H_2O$

   iii) $2Al(OH)_3 \xrightarrow{\;^{\circ}t\;} Al_2O_3 + 3H_2O$

b) i) $Al3+ + 3e^- \rightarrow Al$

   ii) $4\,AlO_3^{3-} + 3C \rightarrow 2Al_2O_3 + 3CO_2 + 12e^-$

   iii) $2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$
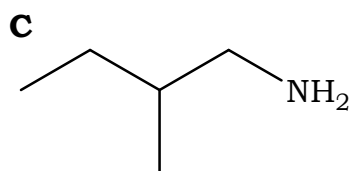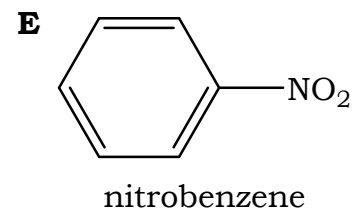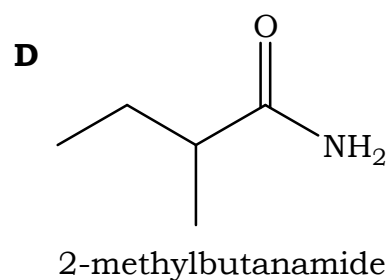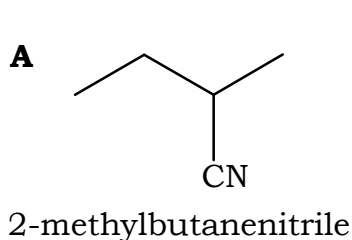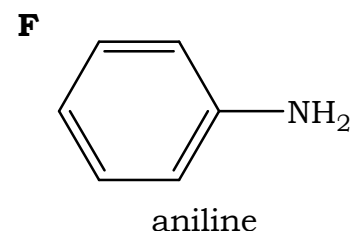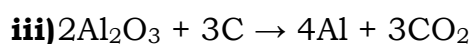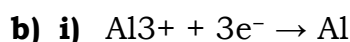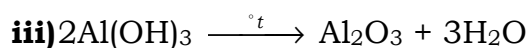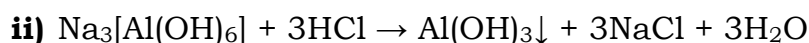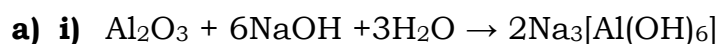
c) $I = \dfrac{3}{1} \cdot \dfrac{8 \cdot 10^5 \text{ g}}{26.98 \text{ g/mol}} \cdot \dfrac{96485 \text{ A} \cdot \text{s/mol}}{7 \cdot 24 \cdot 3600 \text{ s} \cdot 0.950} = 14.9 \text{ kA}$

d) $t = \dfrac{3}{1} \cdot \dfrac{10^6 \text{ g}}{26.98 \text{ g/mol}} \cdot \dfrac{96485 \text{ A} \cdot \text{s/mol}}{3600 \text{ s} \cdot 14938 \text{ A}} = 199.5 \text{ h}$

$\Sigma = 6.00 \text{ V} \cdot 14.9 \text{ kA} \cdot 199.5 \text{ h} \cdot \dfrac{1 \text{ EEK}}{1 \text{ V} \cdot \text{kA} \cdot \text{h}} \approx 17800 \text{ EEK}$

5.

a) $L_M(KClO_4) = \dfrac{1.30 \text{ g} - 0.59 \text{ g}}{138.6 \text{ g/mol}} \cdot \dfrac{1}{(0.0500 + 0.0003) \text{ dm}^3} = 0.102 \text{ M}$

b) $K_{sp}(KClO_4) = [K^+][ClO_4^-] = (0.1018 \text{ M})^2 = 1.04 \cdot 10^{-2} \text{ M}^2$

c) i) $c(ClO_4^-) = 0.01 \text{ M}$

   ii) $[L_M'(KClO_4)]^2 + 0.01 \cdot L_M'(KClO_4) - 0.01036 = 0$,

   $L_M'(KClO_4) = 0.0967 \text{ M}$

d) $L(KClO_4, HClO_4) = \dfrac{0.0967 \text{ mol} \cdot 138.6 \text{ g/mol} \cdot 100}{1000 \text{ cm}^3 \cdot 1.01 \text{ g/cm}^3 - 0.0967 \text{ mol} \cdot 138.6 \text{ g/mol}} = 1.34 \text{ g}$

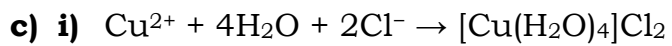**e)** $m(KClO_4) = 1.30 \text{ g} - \dfrac{13.4 \text{ g} \cdot 70 \text{ g}}{996.6 \text{ g}} = 0.36 \text{ g}$

6.

a) i) $2D(OH)_3 \rightarrow D_2O_3 + 3H_2O$;
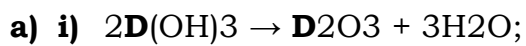
ii) $A_r(D) = (465.96 - 3\cdot16)/2 = 208.98$ g/mol;

iii) D – Bi, bismuth;

b) A – Cu, **B** – Ni, **C** – Mn, **E** – Sb.

c) i) $Cu^{2+} + 4H_2O + 2Cl^- \rightarrow [Cu(H_2O)_4]Cl_2$

ii) $Ni^{2+} + 6H_2O + 2Cl^- \rightarrow [Ni(H_2O)_6]Cl_2$

iii) $Mn^{2+} + 6H_2O + 2Cl^- \rightarrow [Mn(H_2O)_6]Cl_2$
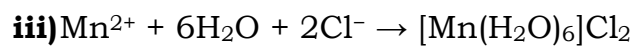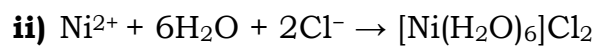
Form XII

1.

a) When normal salt **G** reacts with iodine hydrate, binary salt **AI**$_x$ is obtained

$$M(\text{A}) = 126.9n \cdot {40.25}\Big/{59.75} = 85.48n$$

$n = 1$, $M(\textbf{A}) = 85.48$ g/mol, **A** – Rb, rubidium

b) **B** – RbO_2, rubidium superoxide

C – Rb_2O, rubidium oxide

D – $RbOH$, rubidium hydroxide

E – Rb_2SO_4, rubidium sulfate

F – $RbHCO_3$, rubidium hydrogen carbonate

G – Rb_2CO_3, rubidium carbonate

H – RbI, rubidium iodide

I – RbH, rubidium hydride

X – O_2, oxygen

Q – H_2O_2, hydrogen peroxide

c) **i)** $Rb + O_2 \rightarrow RbO_2$

ii) $RbO_2 + 3Rb \rightarrow 2Rb_2O$

iii) $Rb_2O + H_2 \rightarrow RbOH + RbH$

iv) $RbH + H_2O \rightarrow RbOH + H_2$

v) $2RbO_2 + 2H_2O \rightarrow 2RbOH + H_2O_2 + O_2$

vi) $2RbO_2 + H_2SO_4 \rightarrow Rb_2SO_4 + H_2O_2 + O_2$

vii) $2H_2O_2 \rightarrow 2H_2O + O_2$

viii) $Rb_2SO_4 + Ba(OH)_2 \rightarrow 2RbOH + BaSO_4\downarrow$

ix) $RbOH + CO_2 \rightarrow RbHCO_3$

x) $2RbOH + (NH_4)_2CO_3 \rightarrow Rb_2CO_3 + 2NH_3 + 2H_2O$

xi) $Rb_2CO_3 + 2HI \rightarrow 2RbI + H_2O + CO_2$

2.

a) $k = \dfrac{\ln 2}{t_{1/2}} = \dfrac{0.6931}{1.06 \cdot 10^{11}\ \text{y}} = 6.54 \cdot 10^{-12}\ \text{y}^{-1}$

$t = \dfrac{t_{1/2}}{\ln 2} \ln \dfrac{N_0}{N} = \dfrac{1.06 \cdot 10^{11}\ \text{y}}{0.6931} \cdot 0.1053 = 1.61 \cdot 10^{10}\ \text{y}.$

b) $N_t = N_0 e^{-kt} = 100\% \cdot e^{6.54 \cdot 10^{-12} \cdot 5} = 100\%$

c) it is known from b) that activity of medication hasn't changed during 5 years. It means that its activity is 89,2 Bq/1g.

$$m(\text{Sm}) = 1\ \text{g} \cdot \frac{150.4 \cdot 2}{150.4 \cdot 2 + 3 \cdot 16.0} = 0.862\ \text{g}$$

$$m(^{147}\text{Sm}) = \frac{1.06 \cdot 10^{11} \cdot (365.25 \cdot 24 \cdot 3600)\ \text{s}}{0.6931} \frac{89.2\ \text{dps} \cdot 147\ \text{g} \cdot \text{mol}^{-1}}{1\ \text{g} \cdot 6.02 \cdot 10^{23}\ \text{mol}^{-1}} = 0.105\ \text{g}$$
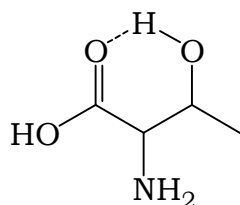
$$\%(^{147}\text{Sm}) = \frac{0.105\ \text{g}}{0.862\ \text{g}} \cdot 100\% = 12.2\%$$

d) $N = \dfrac{10\ \text{g}}{1\ \text{g}} \cdot 89.2\ \text{dps} \cdot (5 \cdot 365.25 \cdot 24 \cdot 3600)\ \text{s} = 1.41 \cdot 10^{12}$.

Problem 3.

a)

X   Y   Z

b)

c)

4.

a) i) $Fe_2O_3 + 6H^+ \rightarrow 2Fe^{3+} + 3H2O$; **ii)** $Fe + 2H^+ \rightarrow Fe^{2+} + H_2$;

    iii) $Fe^{3+} + PO_4^{3-} \rightarrow FePO_4$; **iv)** $Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3$.
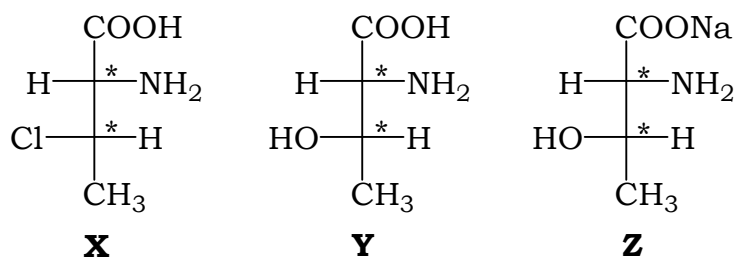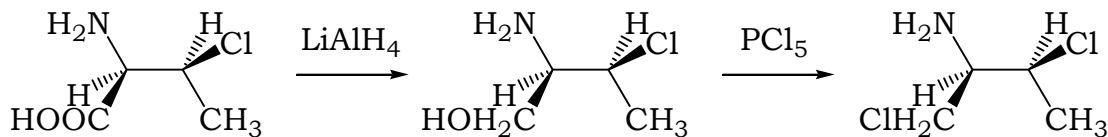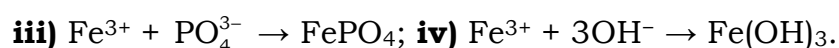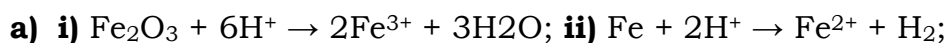
b) i) $\text{pH} = -\log \dfrac{-K_1 + \sqrt{K_1^2 + 4cK_1}}{2} = 1.62$ and **ii)** pH = 7

c) i) $[Fe^{3+}] = \dfrac{K_{sp}[Fe(OH)_3]}{\left(10^{-7}\right)^3} = 4.0 \cdot 10^{-17}\ \text{M}$

    ii) $[Fe^{3+}] = \dfrac{K_{sp}[FePO_4]}{c\alpha} = 3.8 \cdot 10^{-5}\ \text{M}$

5.

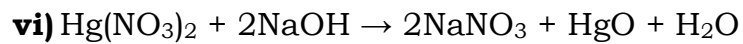**a) A** – Hg, mercury

    B – S, sulphur

    C – SO_2, sulphur dioxide

    D – Na_2S, sodium sulfide

E – $Na_2S_2O_3$, sodium thiosulfate

F – HgO, mercury(II) oxide

G – Hg_2O, mercury(I) oxide

b) **i)** $HgS + O_2 \rightarrow Hg + SO_2$

ii) $S + 2Na \rightarrow Na_2S$

iii) $2Na_2S + 3SO_2 \rightarrow 2Na_2S_2O_3 + S$

iv) $2Na_2S_2O_3 + I_2 \rightarrow 2NaI + Na_2S_4O_6$

v) $KCN + Na_2S_2O_3 \rightarrow KSCN + Na_2SO_3$

vi) $Hg(NO_3)_2 + 2NaOH \rightarrow 2NaNO_3 + HgO + H_2O$

vii) $Hg_2(NO_3)_2 + 2NaOH \rightarrow 2NaNO_3 + Hg_2O + H_2O$

c) $M(\text{HgO}) = 216.6$ g/mol

$M(\text{Hg}_2\text{O}) = 417.2$ g/mol

6.

a) A –

B –

C – Cl

D –

OH

E –

F –

b) i) Br$_2$/$h\nu$ **iv)** 1. B$_2$H$_6$, 2. H$_2$O$_2$

ii) Mg   **v)** SOCl$_2$

iii) OsO$_4$/ROH   **vi)** H$_2$/Pd(BaSO$_4$)

c)