The 28th International Science Olympiad for Young Mathematicians, Physicists and Chemists
November 3, 2015
Chemistry - Form 11

1. FIREWORKS **(10 points)**

Fireworks are beautiful but also very interesting from a chemical point of view. To make fireworks colourful, different salts are added to fireworks.

Salts of metallic elements **A**, **B** and **C** are used in fireworks to obtain blue, red and yellow colour.

1) Complete the chemical equations involving these elements, add missing reaction coefficients, write names of the products and match elements **A**, **B** and **C** to the colours which their salts give to fireworks. **(3 points)**

$\mathbf{B} + O_2 \rightarrow \mathbf{B}_2O_2$

$\mathbf{C} + O_2 \rightarrow \mathbf{C}O$

$\mathbf{A} + O_2 \rightarrow \mathbf{A}_2O$

2) To make fireworks fly, a solid state fuel is needed. Gunpowder has been used for that purpose for more than a thousand years. Charcoal (C), saltpetre (KNO_3) and sulphur (S) react completely if those substances are mixed in 2:21:2 proportions (by mass) respectively.

a) Calculate the mole fraction for each component in the mixture. **(3 points)**

b) Balance the chemical equation for reaction between components of gunpowder:
$KNO_3 + S + C = \mathbf{D} + \mathbf{E} + \mathbf{F} + \mathbf{G}$
There are four products of the reaction. **D** and **E** consist of three different elements, **F** is composed of two different elements and **G** consists of only one element. Sulphur and carbon are oxidized completely during the reaction. All atoms present in **F** are present in **D**. **(4 points)**

2. ACID RAIN **(10 points)**

Rain is considered to be acidic if the pH is lower than 5.6. Acid rain is a big problem since it is capable of destroying sculptures, acidifying soil and lakes and damaging buildings.

1) Acidity in rain is caused by several different chemicals. Among these chemicals are oxides **A** and **B**, which can cause acid rains. **A** forms an acid with molecular weight of 98 g/mol when it reacts with water. **B** forms two acids upon coming in contact with water.

a) What substance is responsible for pH level of 5.6 in normal rain? Write and balance the chemical reactions to prove that solution of this substance is acidic. **(1 point)**

b) Write the names of oxides **A** and **B**, also providing balanced chemical equations for reactions **A** + water and **B** + water. **(2 points)**

c) Show how acid formed from **A** destroys monuments made of marble. Provide net ionic equation for the reaction. **(1 point)**

d) Show how the stronger acid formed from **B** destroys monuments made of bronze. Provide net ionic equations for both components of bronze. **(2 points)**

2) For year 2003 EU had regulated SO_2 emissions to be lower than 25 000 tons per year in Estonia. What if all of it ended up in a lake? Calculate what would be the pH of water in Lake Ülemiste, which provides drinking water for Tallinn, if all the sulphurous acid formed from 25 000 tons of SO_2 ended up in the lake. The volume of Lake Ülemiste is 0.024 km^3. Assume that that pH of water in Lake Ülemiste is 7.0 before acidification. Dissociation constants for H_2SO_3 are $pK_a1 = 1.77$ and $pK_a2 = 7.19$. **(4 points)**

3. QUANTITATIVE RELATIONS IN CHEMISTRY **(8 points)**

One of the principles of green chemistry states: "It is better to prevent waste than to treat or clean up waste after it is formed." Let's examine this principle on the example of hydrazine production and in terms of atom economy (AE).

AE = {molecular mass of desired product} / {molecular mass of all reactants} × 100%

Hydrazine can be produced in the Olin Raschig process from sodium hypochlorite and ammonia: $NH_3 + NaOCl \rightarrow N_2H_4$; in peroxide process from hydrogen peroxide, which is employed as the oxidant: $NH_3 + H_2O_2 \rightarrow N_2H_4$; in urea process from sodium hypochlorite, sodium hydroxide and urea: $(NH_2)_2CO + NaOCl + NaOH \rightarrow N_2H_4$.

a) Complete and balance the net equation for each of the processes. (**3 points)**

b) Calculate the maximum theoretical mass of hydrazine that can be made by reacting 34 g of ammonia with an oxidant. **(1 point)**

c) Calculate the theoretical AE values for the Olin Raschig, peroxide and urea processes assuming that the yield in these process is 100%. **(3 points)**

d) Explain which of the processes is the greenest. **(1 point)**

4. CONDUCTOMETRY **(10 points)**

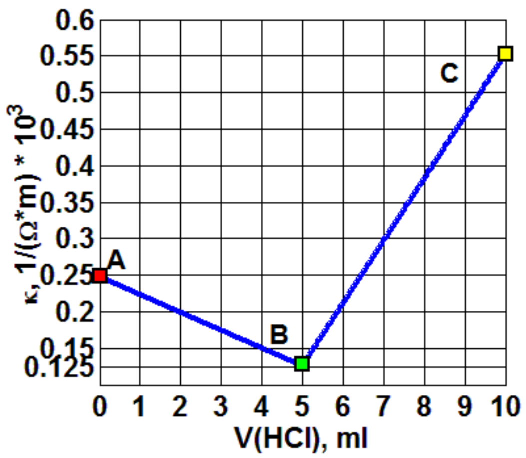
Conductometry is an analytical technique where electrical conductivity of a solution is observed while an analyte is added to the solution. Water itself has a very low conductance but aqueous solutions of salts, acids and bases conduct electricity rather well. Conductivity of solutions is described by the formula

$$\kappa = \lambda_1 * c_1 + \ldots + \lambda_i * c_i$$

where κ is the specific conductance of the solution, λ_i is the molar conductivity of a substance i, and c_i is the concentration of substance i.

Molar conductivities of some common ions are listed in the table:

Ion	$\lambda * 10^3$ 1/(Ω*m*M)
H^+	34.98
OH^-	19.83
Na^+	5.01
Cl^-	7.635



Graph 1

1) A solution (V = 50 ml) containing unknown concentration of NaOH was titrated using a solution of HCl with unknown concentration and *graph 1* was obtained. Using this graph and the table

a) Name all the ions that are present in the solution at different points on the graph (A, B and C). Arrange those in order of increasing concentration. Ions of equal concentration should come one after another in any order. **(1.5 points)**

b) Determine the volume of HCl needed to neutralize the solution. **(0.5 points)**

c) Determine the concentration of NaCl at the equivalence point. **(3 points)**

d) Determine the pH of the original NaOH solution. **(2 points)**

NB! *For all calculations you can make a simplification that λ itself is independent of the concentration, activities of all solutions are 1 and volume of the solution is constant during the titration.*

2) Fill in the missing values in the table for this titration. **(3 points)**

Volume of HCl added	Conductance of the solution	pH of the solution
7 ml		
	$4*10^{-4}/(\Omega*m)$	
		9

5. OXIDATION AND REDUCTION **(10 points)**

Three elements α, β and γ form six binary compounds described below.

At standard conditions, element α has at least three well known allotropes, β has two allotropes (β^1, β^2), and γ has only one allotrope. In two different organic solvents at temperatures well below 0°C, *colorless* β^2 and *red-brown* γ react with each other to form unstable crystals of $\beta_{B1}\gamma_{C1}$ (ω_β = 28.57%) and $\beta_{B2}\gamma_{C2}$ (ω_β = 33.33%). A binary compound of α and γ – $\alpha_{A3}\gamma_{C3}$ (ω_α = 16.67%) – is also unstable; this toxic *gas* readily decomposes into *liquid* $\alpha_{A4}\gamma_{C4}$ (ω_α = 28.57%) and *liquid* γ. Toxic *gas* $\alpha_{A5}\beta_{B5}$ (ω_α = 50.00%) forms in a reaction between *yellow molecular solid* α and *gaseous* β^1. In the presence of a catalyst, $\alpha_{A5}\beta_{B5}$ reacts with β^1 to form liquid $\alpha_{A6}\beta_{B6}$ (ω_β = 60.00%).

1) Write the equations for the described reactions using common chemical symbols. (**5 points)**

2) Write the equations for reactions of the six binary compounds with water. Assume that all reaction products are acids except for one reaction in which solid γ is formed. (**5 points)**

***NB!** For calculations use relative atomic mass rounded to the nearest whole number.*