The 28th International Science Olympiad for Young Mathematicians, Physicists and Chemists
November 3, 2015
Chemistry - Form 12

1. CAMPING GAS **(10 points)**

Three jolly Englishmen decided to go hiking in Dartmoor. They planned on hiking for 2 days and having a warm dinner with tea the first evening. They decided that each one of them will get one cup of tea (200 mL of water per cup) and one pack of British Army Ration Food (containing a number of different nutrients, effectively equivalent to 300 mL of water per ration pack). The ration packs were in their backpacks at a temperature of 20°C, the water for the tea was taken from an icy mountain stream at 5°C. They used a burner and some camping gas (with an average heat transfer efficiency of 50%) to bring the water in the ration packs and for tea to boiling.

Knowing that camping gas is 75% butane and 25% propane by mass, use the following data and **determine how many grams of camping gas was needed** to keep all three jolly Englishmen satisfied in the evening.

Enthalpies of combustion for butane/propane and the specific heat of water:

$\Delta_C H$(butane) = -2877.5 kJ mol^{-1}; $\Delta_C H$(propane) = -2202.0 kJ mol^{-1}; c_p(water) = 4.180 kJ kg^{-1} °C^{-1}

2. ACIDS **(11 points)**

In order to compare the strengths of different acids, a quantity called dissociation constant has been taken into use. For the dissolution of an arbitrary acid HA, the dissociation constant K_a has been defined as following:

$$HA \rightleftharpoons H^+ + A^-$$

$$K_a = \frac{[H^+][A^-]}{[HA]},^1$$

where *[i]* denotes the equilibrium concentration of species *i*. 1 mole of acetic acid and hydrofluoric acid were both dissolved in 1 L of water (thus creating two 1 M acid solutions). It is known that

$K_a(HF) = 7.2 \times 10^{-4}$

$K_a(CH_3COOH) = 1.76 \times 10^{-5}$

Write down the dissociation equations of both acids, **find the pH values** of both solutions and **determine** which of the two acids is stronger.

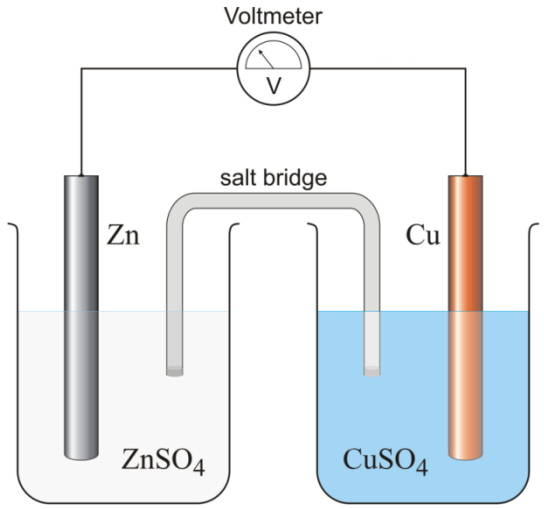
Hint: When an acid HA is dissolved in water, the equilibrium concentrations [H$^+$] and [A$^-$] are equal because they both originate from HA.

[1] Formally the equilibrium concentration of water is in the denominator of the equation. However, when dealing with dilute solutions, $[H_2O] \rightarrow 1$, so it is usually omitted from the equation. Hence K_a is always dimensionless, even though it may not be apparent from the definition.

3. BATTERY **(8 points)**

Jesse and Walter took their RV and drove out of town to relax in the nature. Unfortunately, Jesse forgot to switch off the lights of the vehicle, so the car battery had died by the time they decided to return. Luckily, Walter remembered some of the chemistry he had once learned, so he came up with the idea of building a battery of their own to charge the car battery.

Walter and Jesse managed to gather some copper and zinc pieces. They set up a salt bridge and dipped the pieces in $CuSO_4$ and $ZnSO_4$ solutions (which miraculously happened to be in the trunk). A sketch of the construction looks something like this:



Add the following information on the drawing:

- Charges of the electrodes.
- Movement direction of the electrons.
- Movement direction of the anions.

Moreover, **write down the reactions** taking place on the anode and cathode. **Write down** the full reaction taking place.

It is known that the change in the Gibbs free energy of the reaction taking place under standard conditions is ΔG = -212.04 kJ/mol. The change in Gibbs free energy can be calculated as

$$\Delta G = -nFE$$

where n – number of electrons participating in the reaction

F – Faraday constant, 96485 C mol^{-1}

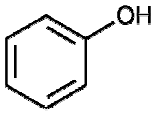
E – electrochemical potential of the cell (V)

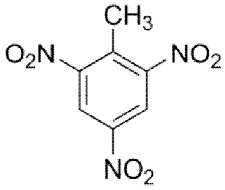
How many of such cells are needed in order to get a battery of 12 V?

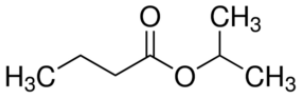
The 28th International Science Olympiad for Young Mathematicians, Physicists and Chemists
November 3, 2015
Chemistry - Form 12

4. BITS AND PIECES FROM ORGANIC CHEMISTRY **(11 points)**

a) Write down the IUPAC names of the following organic compounds:

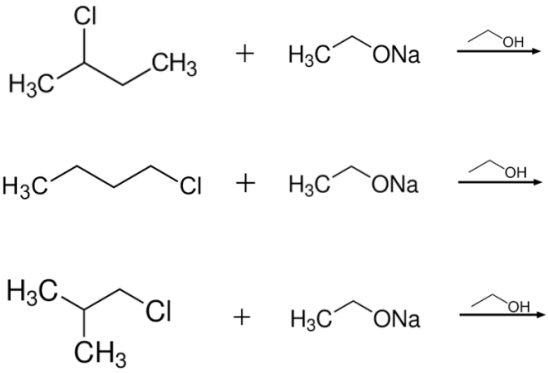






b) 2-chloropropane and sodium ethoxide are reacted in ethanol (which acts as a solvent). There are two main reaction products (in addition to sodium chloride), **A** and **B**. They are formed as a result of two competing reaction mechanisms, with **A** being more dominant at higher temperatures and **B** being more dominant at lower temperatures. **Write down** the reaction, **identify A** and **B** and **write down** their IUPAC names.

Additionally, **identify the main products** of the following organic reactions occurring at lower temperatures (1 main product per reaction).



5. UNKNOWN LIQUIDS **(8 points)**

A student saw six bottles under the fume hood on a beautiful summer day. Each of the bottles contained a different liquid (**A**–**F**) widely used in an organic chemistry lab. It is known that:

1. Liquids **A**, **B**, **D** and **F** are organic, but **C** and **E** are inorganic.
2. **D** and **F** can be prepared by following reactions in the catalytic presence of **C**:

$$\mathbf{A} + \mathbf{B} \xrightarrow{\mathbf{C}} \mathbf{D} + \mathbf{E}$$

$$2\mathbf{B} \xrightarrow{\mathbf{C}} \mathbf{F} + \mathbf{E}$$

3. The molecular formula of **F** is $C_4H_{10}O$.
4. The molar mass of **A** is 60.05 g/mol.
5. **C** is an acid, which contains 65.3% oxygen.

a) Draw all possible isomers of **F**. **(4 points)**

b) Write the formulas of all the mentioned substances **A**–**F**. For organic compounds, write structural formulas. **(3 points)**

c) It is known that during production of **F** from **B**, a side reaction may occur, especially at higher temperatures than 150 °C. Write the reaction equation for this side reaction! **(1 point)**