Task 1

Carbides are binary compounds of carbon with metals. Most carbides readily hydrolyze with water or react with acid solutions, evolving the corresponding hydrocarbons (compounds of carbon and hydrogen). For example:

$$Mg_2C_3 + 4HCl \rightarrow 2MgCl_2 + Gas1\uparrow$$

1. Calculate the volume of **Gas1** evolved from the hydrolysis of 1.00 g of Mg_2C_3 under standard temperature and pressure (STP).

2. Determine the molecular formula and draw the structural formula of **Gas1**. It is known that all three carbon atoms in its molecule are in different chemical environments.

When 3.2 g of carbide **A** reacts with hydrochloric acid, 1.202 L of **Gas1** is evolved (**Reaction 1**) (volume measured at 293 K and 760 mm Hg). After complete combustion of the obtained **Gas1**, 3.606 L of **Gas2** is formed under the same conditions (**Reaction 2**). Gas2 is a typical product of the combustion of organic substances.

When 3.2 g of carbide **B** reacts with hydrochloric acid, 1.202 L of **Gas3** is evolved (**Reaction 3**) (volume measured at 293 K and 760 mm Hg). After complete combustion of the obtained **Gas1**, 2.404 L of **Gas2** is formed under the same conditions (**Reaction 4**). Gas2 is a binary compound and a typical product of the combustion of organic substances.

3. Determine the formulas of substances **A**, **B**, **Gas2**, and **Gas3**. Support your answer with calculations. Write the balanced equations for **Reactions 1-4**.

4. Draw the structural formulas of **Gas2** and **Gas3** molecules.

Alkanes are a class of hydrocarbons with the general formula C_nH_{2n+2}, where n is a natural number.

5. For the combustion of which alkane can the volume of the gaseous combustion products (after cooling to the initial temperature) be equal to the volume of the initial stoichiometric alkane-oxygen mixture? Briefly explain your reasoning.

6. A mixture of an alkane and oxygen (in a 1:10 molar ratio) was ignited in a rigid vessel. After the reaction, when all products were in the gaseous state and the original alkane was completely consumed, the pressure in the vessel was found to be 1.182 times the initial pressure. Determine the formula of the alkane. Briefly confirm your answer with a calculation.

Many other hydrocarbons can be converted into an alkane containing the same number of carbon atoms via catalytic hydrogenation. Into a rigid vessel at constant temperature (initial pressure 760 mm Hg, T = 473 K), 6 L of hydrogen and 2 L of a hydrocarbon C_aH_b were placed. After the hydrocarbon had completely reacted with hydrogen (i.e., when no starting hydrocarbon remained), oxygen was injected into the vessel in an amount 10 times the initial amount (in moles) of the hydrocarbon. After complete combustion (i.e., when no substances reacting with oxygen or excess oxygen remained), the vessel contained only two reaction products, and the pressure was 2660 mm Hg (at 473 K).

7. Determine the formula of the hydrocarbon C_aH_b. Provide your reasoning and calculations.

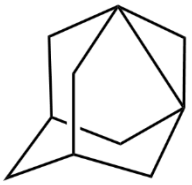
Task 2


[1.1.1]- propellane

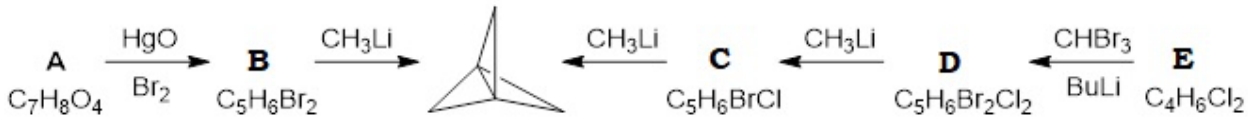
Propellanes are hydrocarbons with an extremely unusual structure, containing two carbon atoms bonded by a single bond that form three bridges consisting of one or more CH_2 bridging groups. The simplest [1.1.1] propellane was first synthesized in 1982, although it was previously considered one of the "impossible" organic molecules due to the presence of two carbon atoms in its structure that form four bonds, all located on the same side of a plane.

1. The numbers in square brackets indicate the number of CH_2 groups in each of the three bridges. Provide the name of one propellane in which the four bonds are also located on the same side of a plane, and the name of one propellane in which this is not the case.

2. 1,3-Dehydroadamantane (structure shown in the figure) contains a fragment of one of the propellanes. Indicate the name of which one.

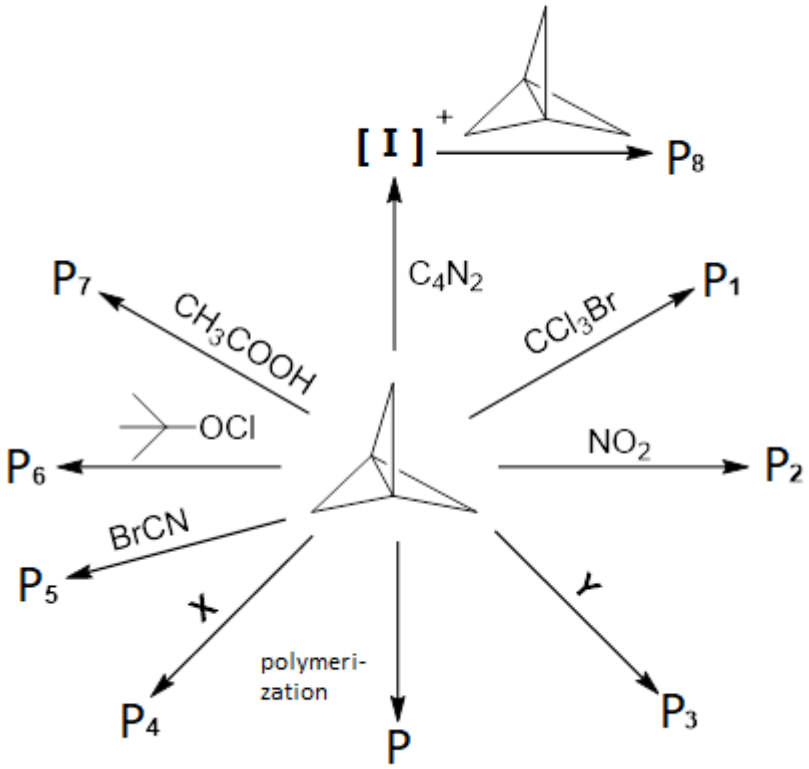


[1.1.1] Propellane is synthesized via one of two methods:



3. Draw the structural formulas of compounds **A** through **D**.

Due to its geometry, the central bond in [1.1.1] propellane differs from the others: for example, it is exceptionally long (1.6 Å!). The central C–C bond of [1.1.1] propellane is weakened and is formed by the overlap of two "pure" p-orbitals, while the remaining C–C bonds can be considered to be formed from hybridized carbon orbitals. Consequently, the central bond readily cleaves in reactions, some of which are shown in the scheme below. The formation of products **P1**–**P6** and polymer **P** presumably proceeds via a radical mechanism, whereas the formation of products **P7**, **P8**, and the short-lived intermediate **I** proceeds via an ionic mechanism. Among the reactions forming **P1**–**P6**, only in the case of **P5** does the process involve more than two simple steps, and the resulting **P5** has a molar mass of 238 g/mol. The reagent C_4N_2, used in the synthesis of **I** and **P8**, is the dinitrile of acetylenedicarboxylic acid.



Additional information is known:

- **X** adds via a P–H bond and contains 16.64% phosphorus by mass.
- **Y** adds via an Se–Se bond, and **P3** contains 41.76% Se by mass.
- The formation of **P7** occurs through addition of H^+, subsequent migration of a cation with an alkyl shift, and addition of CH_3COO^- to the formed cation; **P7** contains one C=C double bond and only one ring.
- The formation of **I** occurs similarly to that of **P7**, however, a new three-membered ring is formed in the process.

- The formation of **P8** occurs similarly to **I**, however, a three-membered ring is cleaved in the process, and **P8** contains only two rings, both of which are four-membered.

4. Draw the structural formulas of **X**, **Y**, C_4N_2, **P**, and **P1**–**P8**.

Task 3

In the gas phase, the familiar equilibrium for the formation of ethyl acetate is established between acetic acid and ethanol:

$$CH_3COOH(g) + C_2H_5OH(g) \rightleftharpoons CH_3COOC_2H_5(g) + H_2O(g)\ (K_1)$$

It turns out that the composition of the equilibrium mixture is significantly influenced by another equilibrium for the formation of diethyl ether:

$$2C_2H_5OH(g) \rightleftharpoons (C_2H_5)_2O(g) + H_2O(g)\ (K_2)$$

1. Write expressions for the equilibrium constants K_1 and K_2 in terms of the equilibrium partial pressures of the mixture components.

2. At a certain temperature, the equilibrium constant for the first reaction is 51.0, and for the second, it is 24.7. Write the expression for the equilibrium constant of the following reaction and calculate its value at this temperature:

$$CH_3COOC_2H_5(g) + C_2H_5OH(g) \rightleftharpoons (C_2H_5)_2O(g) + CH_3COOH(g)$$

At a temperature of 373 K, certain amounts of gaseous ethanol and acetic acid were introduced into an empty vessel. After equilibrium was reached, the amounts of acetic acid, ethanol, ethyl acetate, and water in the mixture were 0.0134, 0.0305, 0.111, and 0.240 moles, respectively.

3. Determine K_1 at 373 K.

4. Calculate the amount of diethyl ether in the equilibrium mixture and the equilibrium constant K_2. Assume only two chemical reactions occur in the system.

5. What amounts of ethanol and acetic acid were taken for the experiment?

In experiments to determine the equilibrium composition of the mixture, polymers containing acid groups are used as catalysts. After maintaining the mixture of ethanol and acetic acid over this catalyst, the gaseous mixture is analyzed using gas chromatography.

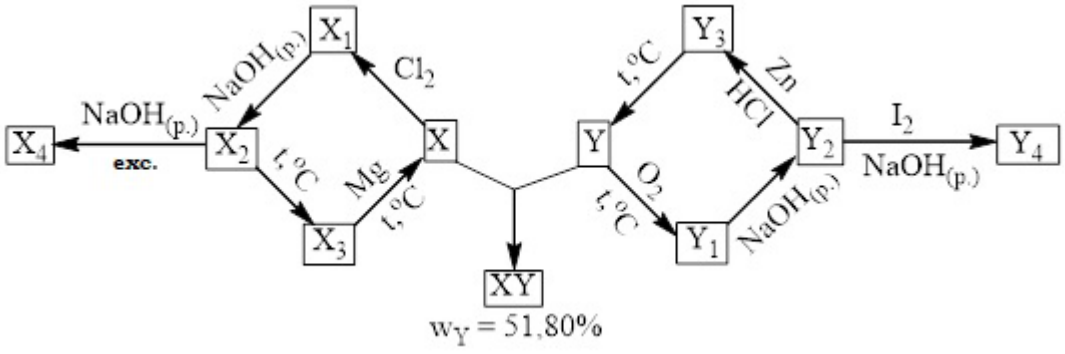
6. How does the presence of the catalyst affect: a) the value of the reaction equilibrium constant, b) the rate constant of the forward reaction, c) the rate constant of the reverse reaction – does it increase, decrease, or remain unchanged?

7. In some experiments, chromatography of the mixture showed the presence of one additional (and only one!) substance not mentioned in the problem. What is this substance if it is lighter than air? Write the equation for its formation in this mixture.

Task 4

Elements **X** and **Y** are located in the fourth period of D.I. Mendeleev's Periodic Table of the Elements. They form a binary compound **XY** in a 1:1 ratio, which is one of the most commonly used semiconductors. The mass fraction of nonmetal **Y** in **XY** is 51.80%.

A reaction sequence involving elements **X** and **Y** is presented below.



1. Determine the elements **X** and **Y**. Name the compound **XY**. Support your answer with a calculation.

2. Determine the formulas of the substances encoded in the scheme. Write the equations for the described reactions (11 reactions). It is additionally known that $\mathbf{Y_3}$ is a readily oxidizable and thermally unstable gas.

3. Which substance has a higher boiling point – $\mathbf{Y_1}$ or $\mathbf{X_3}$? Briefly explain your answer.