

2026/27 Open Chemistry Olympiad Competition Problems
Senior group (Year 11 & 12)
2nd october 2026

1. Elements of a Notorious Group

(10 p)

Elements **X**, **Y** and **Z** belong to the same group. Under standard conditions, element **X** occurs as greyish-black crystals. Salts **A** and **B** of element **X** are added to table salt because **X** is an essential trace element for humans that is present in small amounts in food. Salt **A** is a binary salt that can be prepared by heating salt **B** ($w(\text{X}) = 59.3\%$), during which oxygen is released (**reaction 1**). The water-insoluble salt **C** of element **X** is used in agriculture to condense atmospheric water into clouds, thereby inducing rainfall. In the laboratory, salt **C** can be prepared by reacting the water-soluble salts **A** and **D** ($M(\text{D}) = 169.9 \text{ g}\cdot\text{mol}^{-1}$) (**reaction 2**). A yellow precipitate forms, which gradually darkens upon exposure to light (**reaction 3**). Both elements **Y** and **Z** are gases under standard conditions. **Y** is yellowish-green, whereas **Z** is pale yellow. Element **Y** forms several oxyacids, of which **E** and **F** are strong acids. Acid **E** can be formed by the disproportionation of acid **F**, during which elemental **Y** is also produced (**reaction 4**). In acid **F**, element **Y** has an oxidation state of V.

a) Determine the chemical formulae of compounds **A–F**. (3)

b) Write and balance the equations for **reactions 1–4**. *Hint: disproportionation is a decomposition reaction in which the same element is simultaneously oxidised and reduced.* (2.5)

Elements **X**, **Y** and **Z** form binary compounds with one another. Elements **X** and **Z** form the largest number of such compounds, with the general formula XZ_n .

c) Choose 4 different values of n for which the corresponding binary compounds are stable, taking into account the valence-shell electron configurations of elements **X**, **Y** and **Z**. (1)

d) Choose why elements **X** and **Z** form the largest number of stable binary compounds among all pairs of elements **X**, **Y** and **Z**. (1)

- ☐ **X** and **Z** are the most reactive elements in the group.
- ☐ **X** and **Z** atoms have the largest number of electrons in their outermost shell.
- ☐ Of the possible pairs, **X** and **Z** have the greatest difference in electronegativity.
- ☐ Of the possible pairs, **X** and **Z** have the greatest difference in atomic radii.

Elements **Y** and **Z** form three stable binary compounds **G**, **H** and **I**, where $M(\text{G}) > M(\text{H}) > M(\text{I})$. Compound **H** is used to convert uranium into its gaseous form for uranium enrichment. For this purpose, uranium is reacted with compound **H**, forming a compound **J** of uranium and element **Z**, in which uranium is in its highest oxidation state, and compound **I** (**reaction 5**).

e) Determine the chemical formulae of compounds **G–J**. (1)

f) Write and balance the equation for **reaction 5**. (0.5)

g) Rank the elements **X**, **Y** and **Z**... (1)

- i) ... in order of increasing atomic radius.
- ii) ... in order of increasing electronegativity.

2. Unknown and Hidden Compounds

(11 p)

Gas **X** (whose Latin name means “stranger”) was reacted with halogen Y_2 , and the reaction mixture was heated in a nickel vessel to 400 °C. The described reaction produces a binary compound **A**, which contains 36.66% by mass of halogen **Y**. In compound **A**, the molar ratio of **X** : **Y** is 1 : 4.

a) Identify gas **X**, halogen **Y**, and compound **A** by writing their respective chemical symbols or formulae. (2)

Gas **Z** (whose Latin name means “hidden”) belongs to the same group of the periodic table as **X**. **Z** and Y_2 do not react in the same way as **X** and Y_2 , because the resulting compound is thermodynamically unstable and readily decomposes at higher temperatures. One possible

synthesis method involves using UV radiation at $-196\text{ }^{\circ}\text{C}$, resulting in the formation of the strong binary oxidising agent **B** ($w(\text{Y}) = 31.20\%$) (**reaction 1**). **B** is also the starting point for the preparation of all other compounds of gas **Z**.

When **B** reacts with antimony pentafluoride, an unstable salt **C** is formed (*hint: halogen transfer occurs*), whose cation originates from compound **B** (**reaction 2**). When **B** reacts with compound **D** ($w(\text{halogen}) = 26.05\%$), one of the products is compound **E** (**reaction 3**). Both **D** and **E** are halogen salts and consist of the same elements. The oxidation states of the metal cations in **D** and **E** are atypical for the respective metals; neither oxidation state is higher than IV, and during the reaction it changes by one.

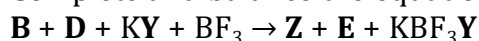
b) Identify gas **Z** and compounds **B–E**. (5)

When **B** reacts with the salt $[\text{HCNH}^+][\text{AsF}_6^-]$, a new salt **F** is formed (**reaction 4**). It is known that **B** adds to the cation $[\text{HCNH}^+]$, forming a new cation with a linear structure that contains one C–H bond.

c) Draw the planar structural formula of the cation of salt **F**. (1)

d) Write and balance the equations for **reactions 1, 2, and 4**. (2)

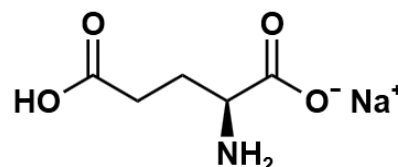
e) Complete and balance the equation for **reaction 3**. (1)



3. Essence of Taste

(10 p)

MSG (monosodium glutamate) is a salt of the glutamic acid found naturally in foods like tomatoes and seaweed. It is used in cooking as a flavor enhancer that intensifies the savory flavor of food, as naturally occurring glutamate does in foods such as stews and meat soups. However, due to it being an acidic salt and containing sodium cations it will change the perceived sourness and saltiness aside from the enhanced taste of umami.



a) Draw the structures of all possible forms/states of glutamic acid in water solution due to dissociation. (2)

The acidity constant (K_a) of the rightmost carboxylic group (C1) is $10^{-2.19}$, leftmost carboxylic group (C5) $10^{-4.25}$, and the amino group (on C2) is $10^{-9.67}$.

b) Calculate the pH of a 1 dm^3 solution prepared by dissolving 23.04 g of MSG. Assume that the volume of the solution does not change upon dissolution. (4)

Assume the pH to be 6.96 if you were unable to solve the previous question.

c) Calculate the concentration ($\text{mol}\cdot\text{dm}^{-3}$) of all neutral forms/states of glutamic acid present in the solution. (1.5)

d) Calculate the mass (g) of baking soda (NaHCO_3) that if added would make the glutamic acid solution neutral. Assume that CO_2 gas is not produced. The dissociation constants of the carbonic acid are $K_{a1} = 4.3\cdot 10^{-7}$ and $K_{a2} = 4.7\cdot 10^{-11}$. (2)

e) Calculate the equivalent mass of NaCl to 23.04 g of MSG in sodium content. (0.5)

4. Water Alkalinity

(9 p)

Alkalinity (L) characterises the concentration of species in water that are capable of binding hydrogen ions. The alkalinity of natural water is mainly determined by CO_3^{2-} , HCO_3^- and OH^- ions, but at higher pH values, other anions of weak acids may also contribute. Alkalinity corresponds to the amount of acid ($\text{mol}\cdot\text{dm}^{-3}$) required to neutralise the ions responsible for alkalinity:

$$L = [\text{OH}^-] + [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}]$$

A natural water sample was analysed in an environmental chemistry laboratory, and its pH was measured to be 9.80. It is known that the total concentration of inorganic carbon-containing species in the water sample is $5.41\cdot 10^{-2}\text{ M}$ and $K_{a2}(\text{H}_2\text{CO}_3) = 4.69\cdot 10^{-11}$.

The following equations may be helpful in solving the problem:

$$\text{pH} = -\log[\text{H}^+] \quad \text{pOH} = -\log[\text{OH}^-] \quad \text{pH} + \text{pOH} = 14$$

- a) Calculate the following for the water sample: **i)** $[\text{H}^+]$, **ii)** $[\text{OH}^-]$, **iii)** $[\text{CO}_3^{2-}]$, **iv)** $[\text{HCO}_3^-]$, and **v)** L ($\text{mol}\cdot\text{dm}^{-3}$). *Hint: use the equation derived from the expression for K_{a2} to calculate $[\text{CO}_3^{2-}]$ and $[\text{HCO}_3^-]$.* (4)

- b) Derive an expression for the alkalinity L of a water sample containing all carbonate and phosphate system ions, as well as hydroxide and hydrogen ions. (0,5)

When determining alkalinity by acid–base titration, two endpoint pH values are used, which can be identified, for example, using phenolphthalein and methyl orange. The water sample is first titrated to pH 8.3; the amount of acid required to reach this pH characterises the *phenolphthalein alkalinity* x_1 ($\text{mmol}\cdot\text{dm}^{-3}$). The sample is then titrated to pH 4.3; the amount of acid required to reach this pH represents the *total alkalinity* x_0 ($\text{mmol}\cdot\text{dm}^{-3}$). Alkalinity is often expressed as the mass concentration ($\text{mg}\cdot\text{dm}^{-3}$) of CaCO_3 or HCO_3^- corresponding to the amount of acid used for the titration. The conversion is based on the stoichiometry of the reactions between CaCO_3 or HCO_3^- and the acid.

A 100 cm^3 sample of weakly alkaline water was provided for titration. The sample was titrated with 0.100 M HCl solution, and the results were recorded in the table below:

Experiment No.	Volume of titrant V (cm^3) required to reach pH 8.3	Volume of titrant V (cm^3) required to lower the pH from 8.3 to 4.3
1	3.87	8.24
2	3.85	8.25
3	3.77	8.31

- c) State the colour of the water sample solution at **i)** pH = 8.3 and **ii)** pH = 4.3. (1)

Indicator	Phenolphthalein	Methyl orange
Transition range (pH)	8.2–10.0	3.2–4.4

- d) Calculate the mean values of **i)** phenolphthalein alkalinity x_1 and **ii)** total alkalinity x_0 . (2)

- e) Express the alkalinity values x_1 and x_0 found in sub-question d) as the corresponding mass concentrations of CaCO_3 ($\text{mg}\cdot\text{dm}^{-3}$). Give your answers to three significant figures. *If you did not obtain values for x_1 and x_0 in sub-question d), use $x_1 = 3$ and $x_0 = 11$.* (1)

Buffer capacity characterises the amount of moles of a strong acid or base that must be added to 1 dm^3 of a buffer solution to change its pH by 1 unit.

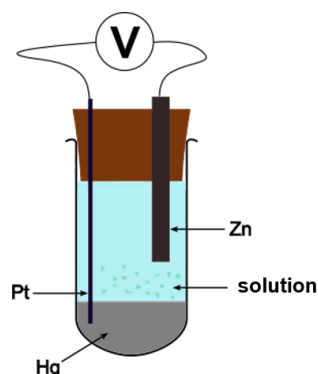
- f) Choose the pH at which the buffer capacity of a carbonate buffer is greatest. (0.5)

- ☐ 4.3
☐ 7.0
☐ 8.3
☐ 10.3

5. Old Electrochemical Cells

(8 p)

The figure shows an electrochemical cell developed by J. L. Clark, which was used in the late 19th century to obtain a stable voltage from the spontaneous reaction occurring in the cell. It could be used to calibrate voltmeters. The cell contained liquid mercury, into which an inert platinum electrode extended. Above the mercury layer was a saturated zinc sulphate solution, which also contained solid crystals of mercury(I) sulphate and zinc sulphate (shown as small dots in the figure). The other electrode was a zinc rod.



For spontaneous reactions, the Gibbs energy, G , which characterises the capacity to do useful work, decreases. The standard Gibbs energy change, ΔG° , and the standard zero-current cell potential, E° , are related by the following equation, where n is the number of electrons involved in the reaction and F is the Faraday constant, $F = 96485 \text{ A}\cdot\text{s}\cdot\text{mol}^{-1}$.

$$\Delta G^\circ = -nFE^\circ$$

The table gives the standard reduction potentials of the relevant redox couples. aq, s and l denote the aqueous, solid and liquid states, respectively.

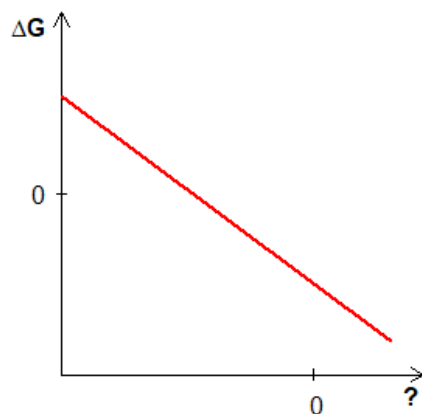
Redox couple	E° (V)
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{Hg}_2\text{SO}_4(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{Hg}(\text{l}) + \text{SO}_4^{2-}(\text{aq})$	+0.62

- Write the reaction equations describing the processes occurring **i)** at the anode and **ii)** at the cathode of the spontaneous reaction taking place in the cell, and **iii)** the corresponding overall reaction. (1.5)
- Determine the charge (+/-) of **i)** the anode and **ii)** the cathode in the spontaneous reaction. (1)
- Calculate the standard zero-current cell potential, E° . (1)

The potential of an electrochemical cell depends on temperature. Measuring the cell potential at different temperatures makes it possible to determine various thermodynamic quantities.

$$\Delta G = \Delta H - T\Delta S \quad \Delta G = -nFE$$

The graph below shows the change in Gibbs energy for a certain reaction as another parameter is varied.



- Select all quantities that could replace the question marks on the graph. (1)
 - ☐ T (absolute temperature)
 - ☐ t (Celsius temperature)
 - ☐ E (cell potential)
 - ☐ n (number of electrons involved in the reaction)

In 1891, E. Weston patented a very similar electrochemical cell. The main difference was that a cadmium electrode was used instead of a zinc electrode, and CdSO_4 was used instead of ZnSO_4 . The Weston cell has a very small temperature coefficient, meaning that its potential does not depend strongly on temperature. The relationship between E and t in the range 0–40 °C is as follows:

$$E_t = 1,01864 - 4,06 \cdot 10^{-5}(t - 20) - 9,5 \cdot 10^{-7}(t - 20)^2 + 1 \cdot 10^{-8}(t - 20)^3$$

where E_t [V] is the potential at temperature t [°C], and 1.01864 V is the potential at 20 °C. Assume that the enthalpy, H , and entropy, S , are independent of temperature.

e) Find the enthalpy change, ΔH , of the reaction occurring in the Weston cell. Assume that $E_t \approx 1,01864 - 4,06 \cdot 10^{-5}(t - 20)$. (2.5)

f) Find the entropy change, ΔS , of the reaction occurring in the Weston cell. Assume that the dependence of the potential on temperature is described by the even more simplified equation, $E_t \approx 1.01864$. (1)

6. Kinetics of Acetone Decomposition (11 p)

Acetone decomposes at higher temperatures (~600 °C) according to the following mechanism:

1. $\text{CH}_3\text{COCH}_3 \rightarrow \text{CH}_2=\text{CO} + \text{CH}_4$
2. $\text{CH}_2=\text{CO} \rightarrow \text{CO} + \text{other products}$

The initial concentration c_0 of the reactant and its concentration c at time τ are related by the integrated rate equations. The form of these equations depends on the reaction order n .

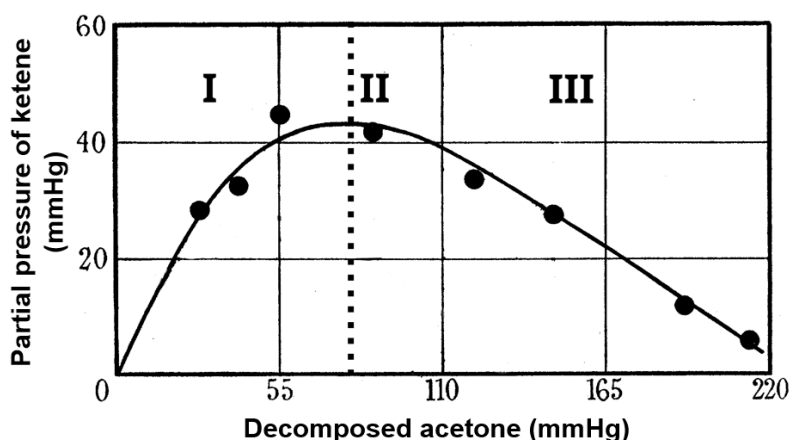
$$\frac{1}{1-n} \left(c_0^{1-n} - c^{1-n} \right) = k(\tau - \tau_0), \quad n \neq 1 \quad \ln c_0 - \ln c = k(\tau - \tau_0), \quad n = 1$$

If the volume is constant, concentrations can be replaced by partial pressures, and vice versa.

a) Write the rate equations for **reactions 1** and **2**. Express the rates v_1 and v_2 in terms of the disappearance of the reactants. Denote the rate constants k with the corresponding subscript. (2)

b) At 595 °C and an initial acetone pressure of 200 mmHg, the partial pressure of acetone decreased to half its initial value in 132 s. Calculate the rate constant k_1 for **reaction 1**. (1)

The graph below shows the dependence of the partial pressure of ketene (an intermediate) on the partial pressure of acetone. The values on the horizontal axis indicate the fraction of acetone that has decomposed.



c) Compare the rates v_1 and v_2 of **reactions 1** and **2** in the regions marked on the graph (I, II and III). Region II is actually located on the dotted line! Insert the correct symbol ($<$, $>$ or $=$) into the inequalities. (1.5)

I	II	III
$v_1 \dots v_2$	$v_1 \dots v_2$	$v_1 \dots v_2$

The graph shows that the maximum partial pressure of ketene is 44 mmHg. At this point, the partial pressure of acetone has decreased by 72.5 mmHg. This state was reached 85.6 seconds after the start of the reaction.

d) Calculate the initial partial pressure of acetone. *If you did not obtain the rate constant k_1 in sub-question **b**), use a value of $3 \cdot 10^{-3}$ (with the correct unit).* (1)

e) Calculate the rate constant k_2 . *If you did not obtain the rate constant k_1 in sub-question **b**) or the initial pressure of acetone in sub-question **d**), use $k_1 = 3 \cdot 10^{-3}$ (with the correct unit) and $p_0 = 300$ mmHg. Hint: the graph shows a region where $v_1 = v_2$; substitute the corresponding rate equations for the rates in this expression.* (2.5)

The dependence of the reaction rate constant k on various factors is described by the following equation:

$$k = A \cdot \left(\frac{1}{2}\right)^{E_a/(0.693RT)}$$

E_a denotes the activation energy, i.e. the minimum energy that must be supplied to the system for the reaction to occur. A is a constant related to the frequency of collisions between particles. $R = 8.314 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ is the universal gas constant. T is the temperature.

The rate of acetone decomposition was measured at different temperatures. The data obtained are given in the table below:

Temperature (t) [$^{\circ}\text{C}$]	Rate constant (k) [s^{-1}]
542	0.000415
552	0.000693
562	0.00116
582	0.00301
602	0.00730
612	0.0116
622	0.0182

f) Select the axes on which the measured data give a linear relationship. T denotes the absolute temperature, while t denotes the Celsius temperature. (1)

☐ k vs t	☐ $\ln k$ vs t	☐ $\ln k$ vs $\ln T$	☐ $\log(k^{-1})$ vs T^{-1}
☐ $\log k$ vs t^{-1}	☐ k^{-1} vs T	☐ $\ln k$ vs t^{-1}	☐ $\ln k$ vs T^{-1}

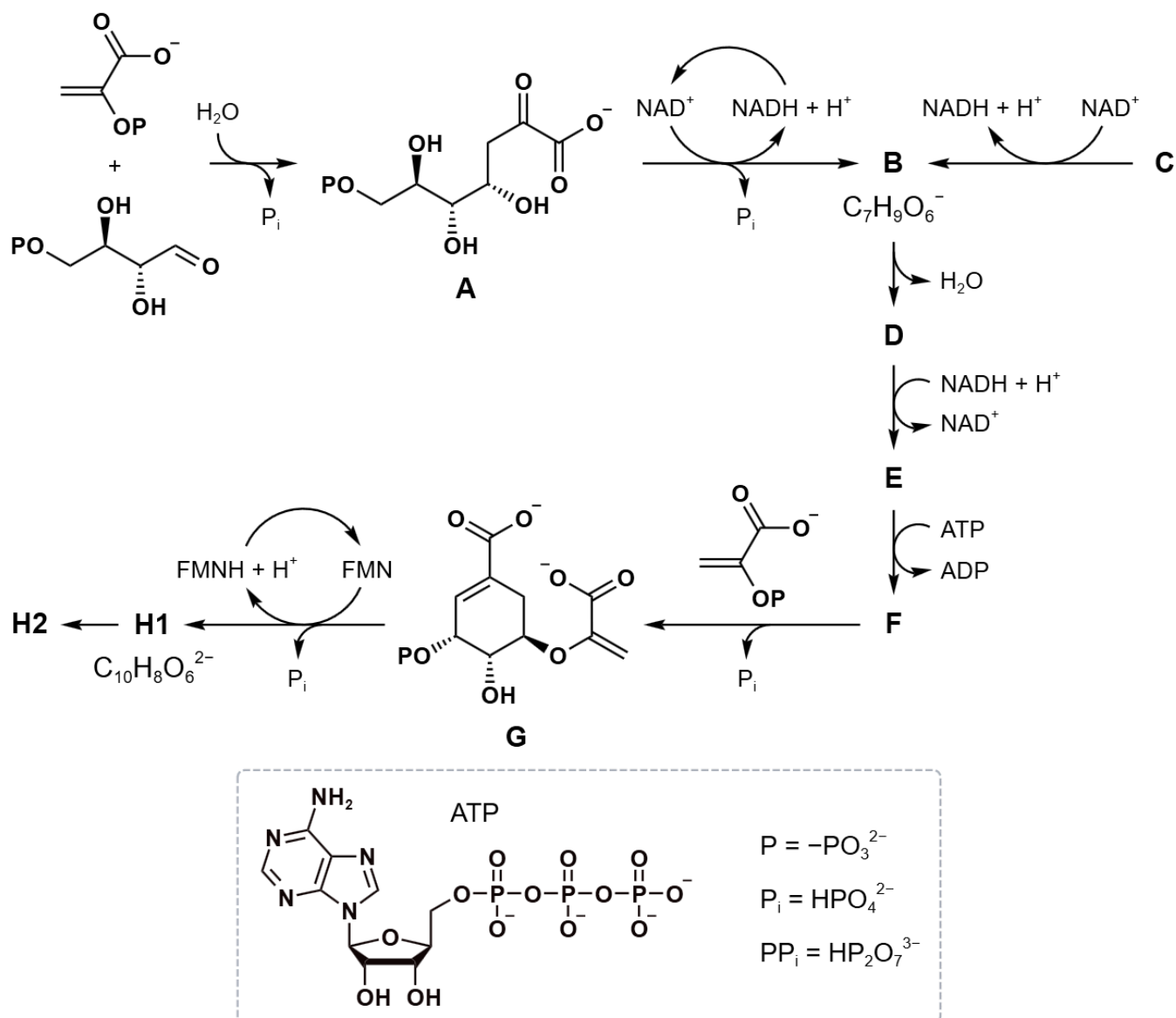
g) Calculate the activation energy E_a of the reaction. Assume that it does not depend on temperature within the measured temperature range. (2)

7. Unusual Metabolites

(10 p)

The biosynthesis of metabolites essential for the life processes of many bacteria, archaea, fungi, and algae involves the reactions shown in the scheme below, whose end products **H1** and **H2** serve as precursors for several aromatic amino acids and lipid-soluble vitamins.

Biochemical reactions are catalyzed by enzymes with a protein-based structure, whose function is supported by non-protein coenzymes such as ATP (adenosine triphosphate), NAD^+ (nicotinamide adenine dinucleotide), and FMN (flavin mononucleotide). ATP is a donor of the phosphoryl group P ($-\text{PO}_3^{2-}$), which acts as a good leaving group P_i (HPO_4^{2-}) in hydrolytic substitution reactions. ATP can be hydrolyzed either to ADP (adenosine diphosphate), donating one phosphoryl group, or to AMP (adenosine monophosphate), during which a pyrophosphate group PP_i ($\text{HP}_2\text{O}_7^{3-}$) is formed. NAD^+ and FMN participate in redox reactions as hydrogen carriers, acting as reducing agents – NAD^+ in the form of a hydride ion (H^-), while FMN acts in the form of a hydrogen radical ($\text{H}\cdot$).



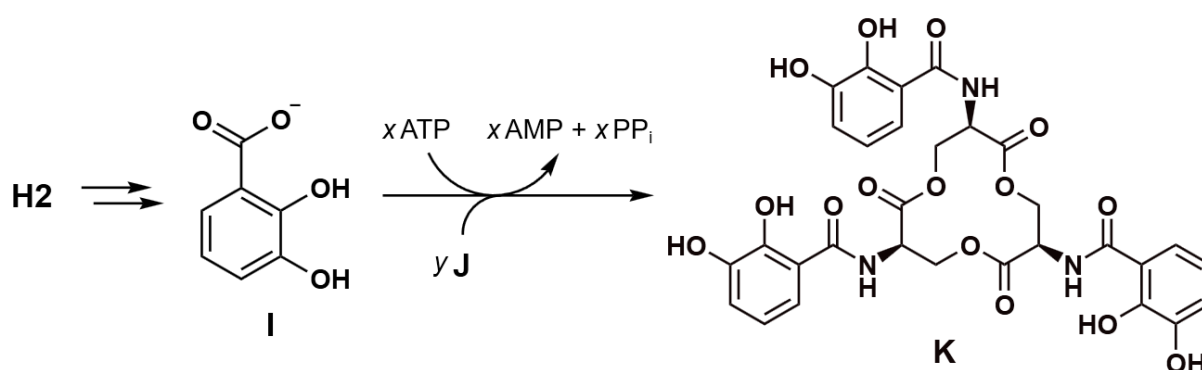
Hints:

- During the **A** → **B** reaction, a ring with three chiral centers is formed.
- Compound **C** contains four chiral centers.
- In the reactions **A** → **B** and **G** → **H1**, the coenzymes NAD⁺ and FMN first act as hydrogen acceptors and subsequently as hydrogen donors again.
- The enzyme hydroxymutase catalyzes **H1** → **H2**, carrying out the rearrangement of a hydroxyl group.
- **H1** and **H2** are positional isomers.

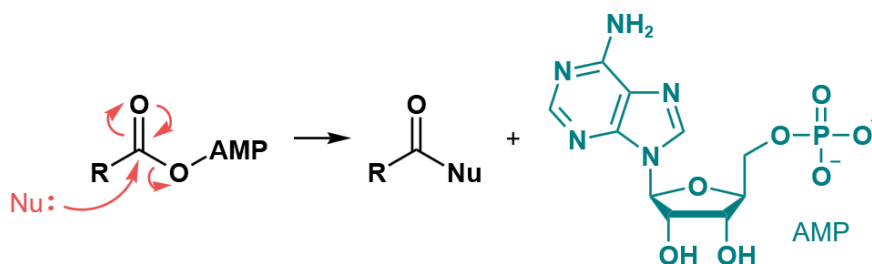
a) Choose the name reaction that the biosynthetic reaction of compound **A** resembles. (0.5)

- ☐ Aldol reaction
- ☐ Claisen condensation
- ☐ Dieckmann condensation (intramolecular Claisen condensation)
- ☐ Michael addition (1,4-addition reaction)

Certain bacteria synthesize the secondary metabolite **K** from compound **H2**, which helps them bind and take up iron (in the form of Fe³⁺ ions) from their surrounding environment. Metabolite **K** is formed by the reaction of catechol **I** with the *L*-amino acid **J**.



In successive reactions, the carboxyl groups are activated using ATP (i.e., they are made more reactive toward nucleophiles by converting them into better leaving groups) for subsequent nucleophilic acyl substitutions. Nu = nucleophile.

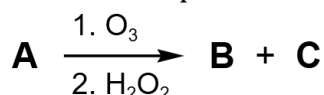


- b) Draw the structural formulas of **B**, **C**, **D**, **E**, **F**, **H1**, **H2**, and **J**. When drawing the structural formulas, the stereochemistry of the chemical bonds does not need to be shown. (8)
- c) Determine the denticity of compound **K** if all catechol groups participate in chelation with one iron ion. (0.5)
- d) Determine the values of the coefficients x and y in the reaction $\text{I} \rightarrow \text{K}$. (1)

8. The Carboxylic Acid Mystery

(9 p)

Upon oxidative ozonolysis of a certain monoprotic carboxylic acid **A**, two new carboxylic acids were obtained: the monoprotic acid **B** and the diprotic acid **C**.



Titration of 2.000 g of **C** separated from the reaction mixture required 17.44 cm³ of 10% KOH solution ($\rho = 1.090 \text{ g}\cdot\text{cm}^{-3}$). It is known that **A** contains an unbranched carbon chain and reacts with bromine in a 1 : 1 molar ratio, forming compound **D** ($w_{\text{bromine}} = 52.92\%$).

- a) Calculate:
 - i) the molar mass of carboxylic acid **A** ($\text{g}\cdot\text{mol}^{-1}$). (1.5)
 - ii) the amount of carboxylic acid **C** reacting with KOH (mol). (1.5)
- b) Write the molecular formulas of the carboxylic acids i) **C** and ii) **A**. (4)
- c) Draw the structural formulas of the carboxylic acids **A**, **B**, and **C**. (1.5)
- d) Choose which reagent or combination of reagents is suitable for the qualitative identification of carboxylic acid **A** instead of bromine. (0.5)
 - ☐ Jones reagent ($\text{CrO}_3/\text{H}_2\text{SO}_4$)
 - ☐ Dilute HCl solution
 - ☐ Cold, dilute KMnO_4 solution
 - ☐ 1. LiAlH_4 , 2. H_3O^+

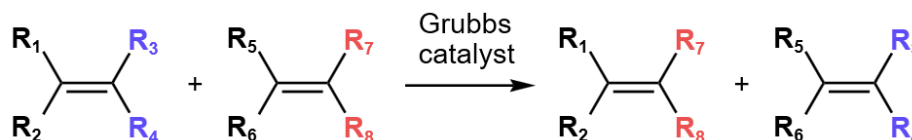
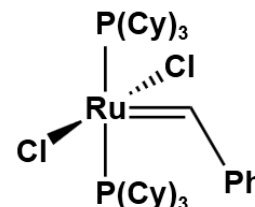
9. Transition Metals in Organic Chemistry

(12 p)

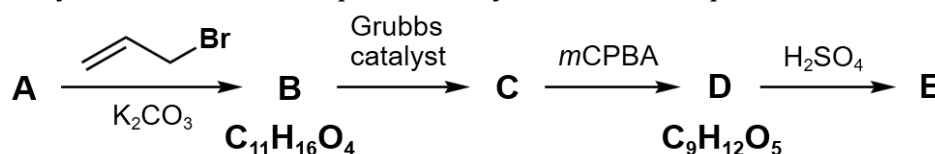
The formation of new carbon-carbon bonds is one of the cornerstones of modern organic chemistry. This can be achieved, for example, using organometallic compounds. In this problem, we will become familiar with some of them.

Grubbs catalysts

Grubbs catalysts are a series of different ruthenium complexes named after Robert H. Grubbs. The first-generation Grubbs catalyst (shown on the right) was synthesized in 1995. It catalyzes the olefin metathesis reaction, the general form of which is shown below, where R_1 – R_8 represent different alkyl groups.



The Grubbs catalyst is used, for example, in the synthesis of compound E.



Hints:

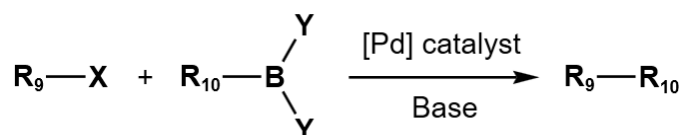
- The systematic name of compound A is dimethyl propanedioate.
- The reaction $B \rightarrow C$ is intramolecular.
- mCPBA (meta-chloroperoxybenzoic acid) "adds" an oxygen atom across the alkene double bond, forming a three-membered epoxide ring.
- The reaction $D \rightarrow E$ is a hydrolysis reaction.

a) Draw the structural formulas of compounds A–E.

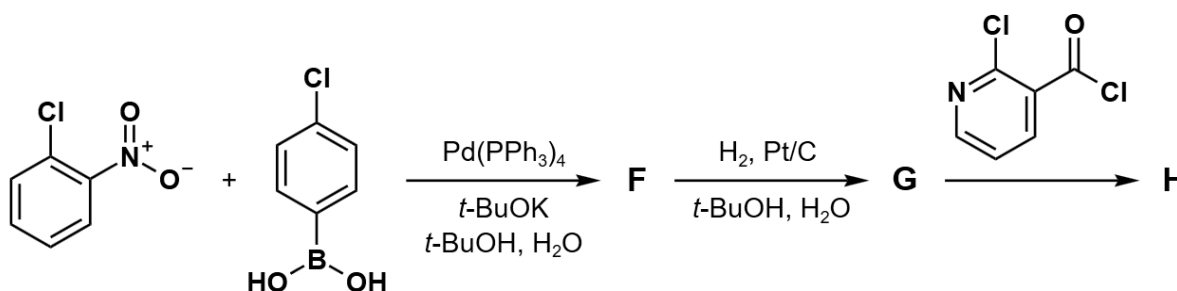
(4)

Suzuki reaction

In the Suzuki reaction, a palladium complex is used as a catalyst to form a new carbon-carbon bond between a halide (RX) and an organoboron compound (BY_2R). The reaction was first discovered by Akira Suzuki in 1974, and he was awarded the Nobel Prize in 2010 for this work. In the reaction scheme, X is a halogen atom (Cl, Br, or I), Y represents certain substituent groups, and R_9 and R_{10} are alkyl groups.



Compound H is a known fungicide that protects plants against fungal diseases. Its synthesis begins with 1-chloro-2-nitrobenzene.



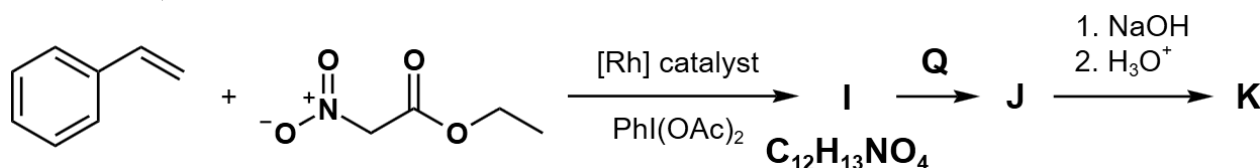
b) Draw the structural formulas of compounds F–H.

(3)

- c) Choose which new functional group is formed in the reaction $\mathbf{G} \rightarrow \mathbf{H}$. (1)
- ☐ Alkyl group
☐ Amino group
☐ Amide
☐ Aldehyde

Rhodium catalysts

Rhodium forms several complex compounds in different oxidation states, which are used as catalysts in reactions involving alkenes. One of these catalysts can be used to synthesize the amino acid **K**, which has a distinctive structure.



Hint:

- Compound **I** contains a three-membered ring.
- d) Draw the structural formulas of compounds **I–K**. (3)
- e) Choose which of the following reagent(s) would be suitable as **Q**. (1)
- ☐ Zn, HCl
☐ KMnO_4
☐ O_3
☐ KCl