BOSWELL-BÈTA

James Boswell Exam

Chemistry VWO

Date:	Example exam 1
Time:	1:00 pm – 4:00 pm (3:00 hours)
Number of questions:	5
Number of subquestions:	28
Number of appendices (hand-in):	4
Total number of points:	75

Important:

- Write your name on **every sheet of paper** that you hand in.
- Use a separate sheet of paper for each exam question.
- For each question, show how you obtained your answer by means of reasoning and/or calculation. No points will be awarded for an answer without an explanation.
- Write legibly and **in ink/unerasable pen**. Correction fluid and correction tape are not permitted. The use of a pencil is only allowed for drawings.
- You may use the following:
  - A non-graphing calculator.
  - BINAS 5th or 6th edition (either in English or Dutch); please indicate which edition you are using.
  - Drawing equipment, for graphs or structural formulas.
  - An English dictionary.

Question 1: Methanal

The substance methanal (formerly known as formaldehyde) seems to be a simple substance. But chemically it turns out to be completely different.

2p. **a.** Give the structural formula of methanal.

Gaseous methanal occurs in the form that you have indicated in your answer to question a. In this form methanal is categorized as irritant: it will temporarily harm skin, but permanently harm lungs and eyes.

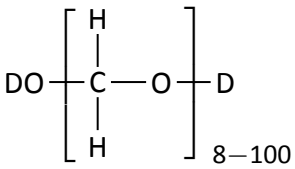
Liquid methanal, however, forms all kinds of complex structures. One of these is the cyclic compound 1,3,5-trioxane with formula $(CH_2O)_3$.

3p. **b.** Give the structural formula of 1,3,5-trioxane, in which three molecules of methanal form the cyclic structure $(CH_2O)_3$. No other products are formed in the formation of this trimer.

When a small amount of water is present, methanal forms a polymer named para-formaldehyde. Depending on the amount of water, methanal can form chains ranging from 8 to 100 molecules of methanal in a chain. The water is used at the terminal ends of the polymer chains.

Ellen wants to experimentally determine the average degree of polymerization in para-formaldehyde. To achieve this, she prepares a sample of methanal to which she adds a small amount of deuterated water (D_2O), forming deuterated para-formaldehyde.

The structural formula of deuterated para-formaldehyde is depicted below.



This sample is measured using an H-NMR instrument. The result indicates that the average molecular mass in the polymer equals 440.4 g/mol.

1p. **c.** Explain what is meant by the average molecular mass of a polymer.

4p. **d.** Calculate the average degree of polymerization in para-formaldehyde. The D atom must be interpreted as a deuterium atom ^2H.

When more water is present, the polymer molecules of para-formaldehyde dissociate again forming a solution of methanal in water which is known as “formalin”, or “strong water”. In biology formalin is used as a preservative for dead tissue.

Formalin is a saturated solution of methanal in water with has a density of 0.815 kg/L. It contains 40 volume-% methanal, the rest is water.

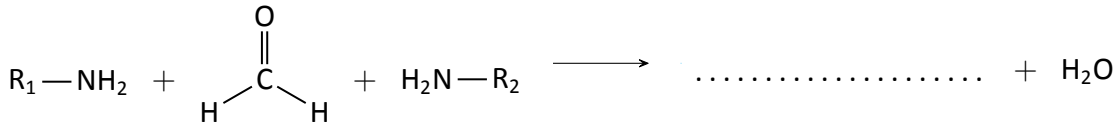
4p. **e.** Calculate the mass of methanal in 1.0 L of formalin.

By inhibiting the enzymatic activity of bacteria, formalin prevents the degradation of dead tissue. The methanal binds to the free NH_2-groups in the amino acids of the bacterial enzymes.

3p. **f.** Provide three-letter codes of two amino acids that may be bonded by methanal. Use Binas table 67C.

In this reaction two NH_2-groups are bonded to methanal while releasing a molecule of water.

This reaction is partially given below.

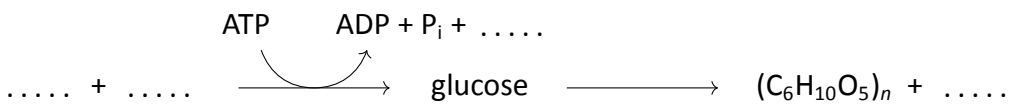


2p. **g.** Draw the structural formula of the missing molecule right of the arrow.

Question 2: Akzo Nobel

Akzo Nobel is an originally Dutch multinational that produces paints and coatings as well as specialized chemicals. The company was formed through the fusion of Nobel Industries and the Dutch company Akzo. At the time, Nobel Industries was specialized in support chemicals for the paper industry.

Paper consists mainly of cellulose ($(C_6H_{10}O_5)_n$), which is formed by plants in multiple steps. The first step in the formation of cellulose is the formation of glucose by photosynthesis, and in a subsequent reaction the plant converts glucose into the cellulose polymer.



The incomplete reaction diagram is also given in the Appendix.

2p. **a.** On the Appendix, complete this reaction diagram. It is not required to balance the reaction equations.

When paper is recycled it is first decolorized an then bleached, before it can be sold again as white paper. The reaction that decolorizes waste paper is a redox reaction, in which the dithionite ion ($S_2O_4^{2-}$) is used as a reducing agent.

2p. **b.** Use a calculation to show what the oxidation number is of sulfur in a dithionite ion.

In redox reactions, the dithionite ion can react as either a reducing agent **or** as an oxidizing agent. As a reducing agent it forms hydrogen sulfite. As an oxidizing agent it forms thiosulfate.

4p. **c.** Give the half reactions for both situations in an alkaline environment.

Formulate your answer as follows:
As oxidizing agent the half reaction for dithionite in an alkaline environment is: . . . . . .
As reducing agent the half reaction for dithionite in an alkaline environment is: . . . . . .

After cellulose, lignin is the most abundant organic material on earth. The strength of wood, for instance, is the result of the composite material which is formed through the interaction between cellulose and lignin.

In the past, chlorine was used as an oxidant to degrade lignin and to bleach wood fibers. However, this process produced poisonous organic chloro compounds. These compounds bind to so-called transcription factors on DNA, which result in over-expression of selective parts of the DNA by RNA-polymerase during transcription.

2p. **d.** Explain why and how this can have a large impact on the animal cell.

Nowadays waste paper is bleached using a solution of sodium sulfide in a diluted hydrogen peroxide solution. Hydrogen peroxide is a weak acid that forms the following equilibrium in water:

$$H_2O_2 + H_2O \rightleftharpoons HOO^- + H_3O^+$$

The HOO^- anion hardly reacts with cellulose, but it does react with the carbonyl groups in lignin and other organic compounds that cause colorization, leading to colorless products.

3p. **e.** Using above reaction, explain what the function is of adding sodium sulfide. In your argument use a piece of information about hydrogen peroxide given in Binas 49.

Many OH-groups are present in cellulose molecules, so that hydrogen bonds form between cellulose molecules. However, not all OH-groups in cellulose are involved in the formation of hydrogen bonds between cellulose molecules. Some of the OH-groups bond to water molecules instead.

After drying, a typical type of paper still contains on average 9.0mass percent water.

4p. **f.** Calculate the average number of water molecules in 100 g of this type of paper that is bonded per OH-group. In your calculation assume that each glucose monomer contains 3 OH-groups.

Question 3: Aniline

Aniline is an aromatic compound with the systematic name benzene amine.

2p. **a.** Give the structural formula of aniline.

Aniline like other amines, has a very unpleasant smell. It smells like rotten fish. Nevertheless, aniline plays an important role in the industrial chemistry.

Aniline has a pK_b equal to 9.4.

1p. **b.** Give the equilibrium reaction showing that aniline in water forms an alkaline solution. Use the shorthand notation $R-NH_2$ for aniline.

4p. **c.** Calculate the pH of a 0.1 M solution of aniline.

In comparison to other non-aromatic amines aniline is much less alkaline. This is caused by the fact that the free electron pair of the amino group is delocalized into the benzene ring.

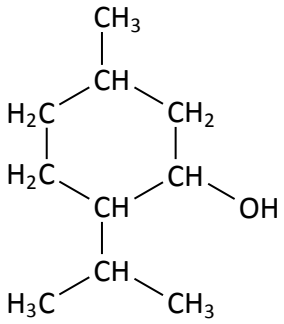
3p. **d.** Explain that due to this delocalization aniline is much less alkaline than for instance methane amine. In your answer first draw the Lewis structure of aniline and subsequently explain what happens when the amino group accepts a H^+ ion, and what the effect of delocalization will be.

Question 4: Peppermint

Peppermint is available in many countries as a breath freshening candy. Peppermint has a characteristic taste that many people like. The same flavor is also available in chewing gum, toothpaste, and cough drops. Mint tea has become a popular drink in recent years. Even in some desserts peppermint flavor plays an important role.

The compound responsible for the typical flavor of peppermint, toothpaste, cough drops and mint tea is menthol. Menthol is found in large quantities in the plant *Mentha balsamea* (wild type), better known as Mint.

The structural formula of menthol is depicted below:



The official IUPAC-name of menthol is 5-methyl-2-(prop-2-yl)-cyclohexane-1-ol.

5p. **a.** Encircle all the different parts of the molecule that correspond to parts of the name on the appendix. Also explain why the groups were assigned the numbers in the name as given. The prefix (1R,2S,5R) doesn't have to be explained.

There are multiple stereo isomers of 5-methyl-2-(prop-2-yl)-cyclohexane-1-ol.

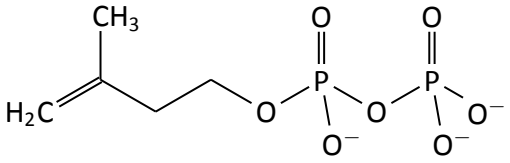
1p. **b.** Explain how many stereo isomers there exist of menthol.

Menthol, as it appears in the plant Mint and as is used in peppermint and toothpaste, is the specific isomer in which the methyl group and hydroxy group form a *cis*-orientation. The propyl group and methyl group are in a *trans*-orientation.

On the Appendix, the incomplete spatial drawing of the structural formula of menthol is drawn. Only the hydroxyl group has been drawn.

3p. **c.** On the appendix, finish the drawing by adding the remaining methyl- and propyl groups in their correct orientations.

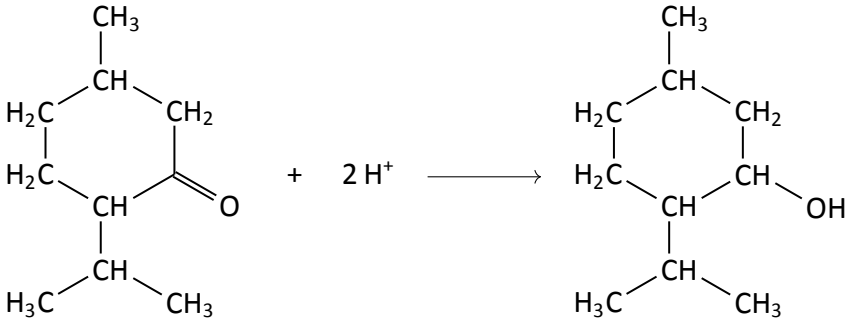
In the plant *Mentha balsamea* (wild type) menthol is synthesized from the substance IPP, iso pentenyl-pyrophosphate. The structural formula of IPP is depicted below:



In IPP, two phosphate groups are attached through a condensation reaction with molecule X and two phosphate groups.

3p. **d.** Draw the structural formula of molecule X, and provide the systematic name of the substance. Molecule X does not contain phosphate groups.

The final step in the synthesis of menthol by the plant *Mentha balsamea* (wild type) is the conversion of menthon into menthol:



This is an unbalanced redox halfreaction.

2p. **e.** Balance the half-reaction and explain that menthon acts as the oxidizing agent.

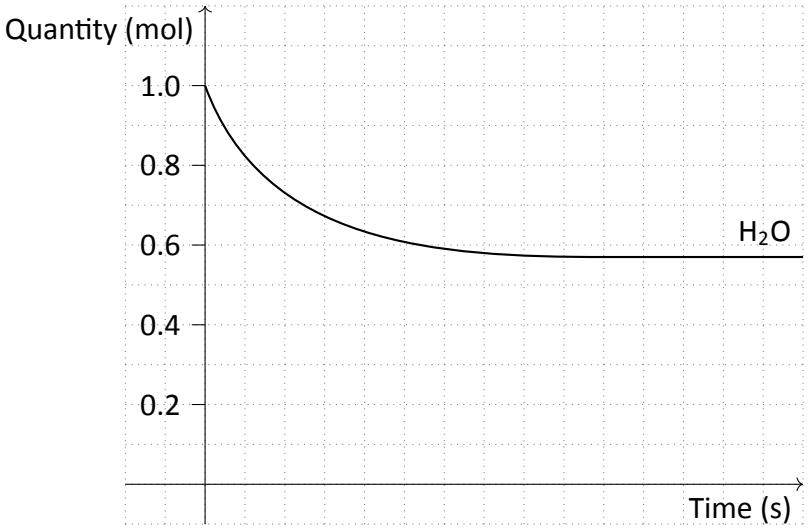
Question 5: A gas equilibrium

In a reaction chamber of 20 L, which is supplied with a manometer (pressure meter), the following gases are brought together: 0.5 mol carbon monoxide and 1.0 mol water vapor.

The chamber is subsequently set to a temperature of 750 K. In the equilibrium that sets in, hydrogen is also formed.

3p. **a.** Give the complete equilibrium reaction, and state the equilibrium law expression.

The graph below depicts the change (in mol) of water vapor while equilibrium sets in.



On the Appendix, you can find an enlarged version of the same graph.

3p. **b.** On the appendix, sketch the change (in mol) of the other substances with time while equilibrium sets in.

3p. **c.** Calculate the pressure that the manometer will indicate at equilibrium. Give your answer in atmosphere.

2p. **d.** Based on the concentrations at equilibrium, calculate the value of the equilibrium constant at 750 K.

When the temperature is lowered to 500 K, the value of the equilibrium constant increases. This means that the righthand side of the equilibrium is exothermic.

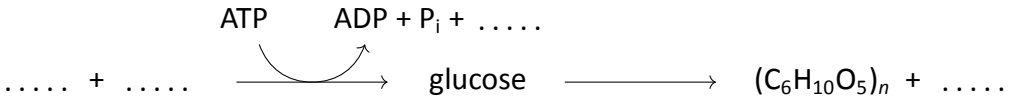
2p. **e.** Explain this statement.

When we further lower the temperature down to room temperature (25 °C), then we can show by calculation using values in Binas that the righthand side is indeed the exothermic side.

2p. **f.** Give this calculation, and show that the righthand side is the exothermic side.

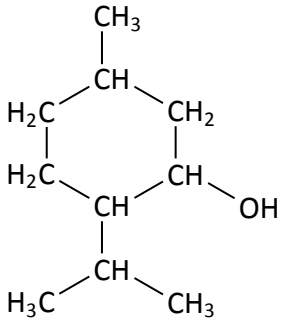
Candidate name: _____

Question 2.a



DO NOT FORGET TO HAND IN THIS APPENDIX

Question 4.a



The numbers (in bold) in the name can be explained by:

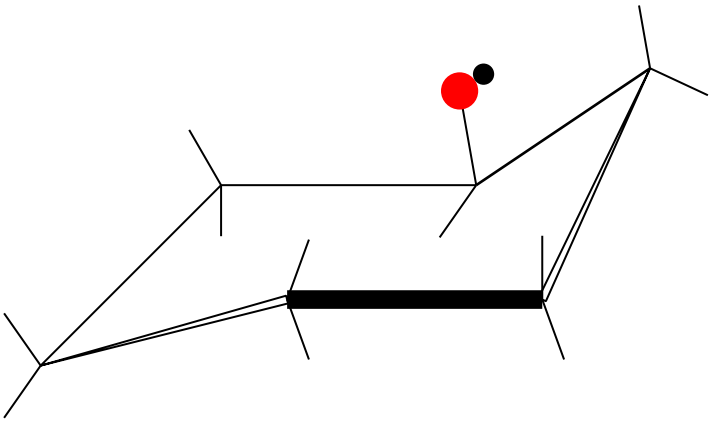
5-methyl . . . . . .

2-(prop-2-yl) . . . . . .

prop-**2**-yl . . . . . .

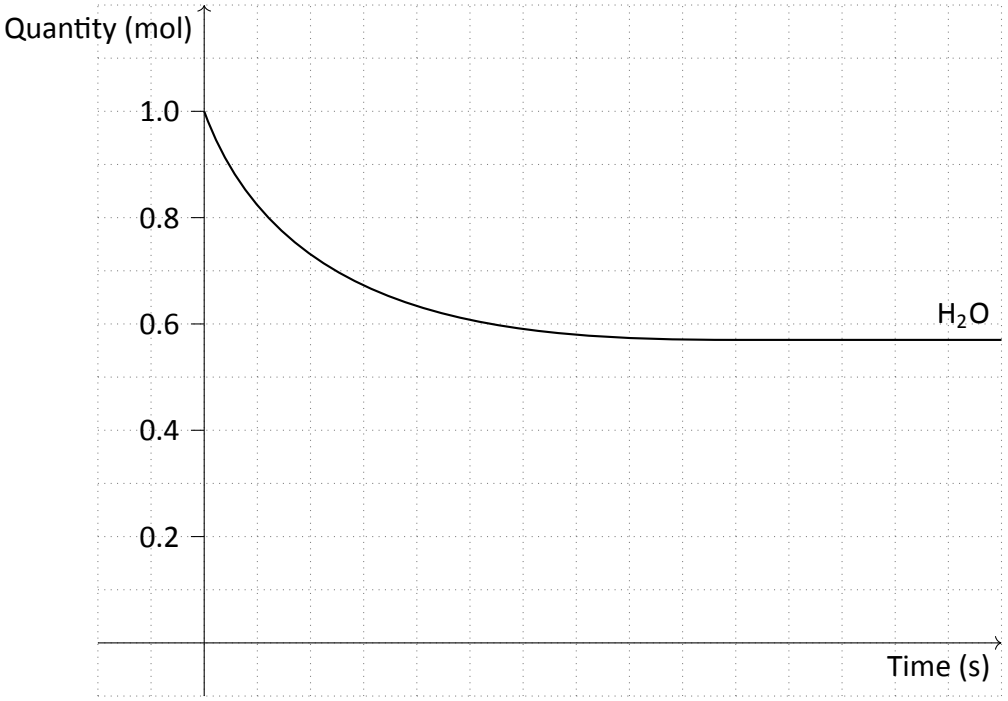
1-ol . . . . . .

Question 4.c



Note: the last questions of this exam are on the next page.
DO NOT FORGET TO HAND IN THIS APPENDIX

Question 5.b



DO NOT FORGET TO HAND IN THIS APPENDIX