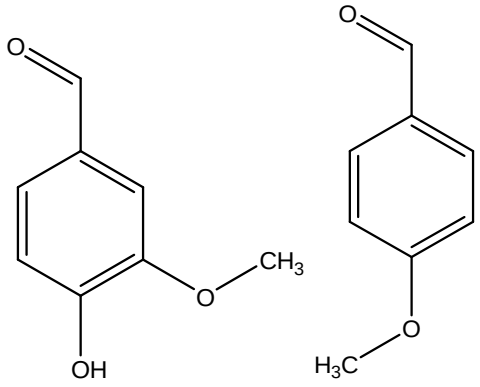
PRACTICAL PROBLEMS

PROBLEM 1 (Practical)

Synthesis of 2,4-dinitrophenylhydrazones

Hydrazones belong to the class of *imines*, which contain a nitrogen-nitrogen single bond adjacent to a carbon-nitrogen double bond. Hydrazones are formed when NH_2-containing hydrazine reacts with aldehydes or ketones under appropriate conditions. Because the hydrazone derivatives of the carbonyl compounds are often stable, crystalline, highly coloured solids, they are used to confirm the identity of aldehydes and ketones.

In this task you will have to identify two substituted benzaldehydes (shown below) by studying the products of their reactions with 2,4-dinitrophenylhydrazine.



Reagents

- 2,4-Dinitrophenylhydrazine
- Sulfuric acid, concentrated
- Aldehyde solution, 1 mmol in ethanol
- Ethanol
- NaOH solution
- Acetone

Procedure

Equip one 50 cm^3 beaker with a magnetic bar. Fix the beaker on the stirrer using the metal ring attached to the stand. Place the content of vial (200 mg of 2,4-dinitrophenylhydrazine) into the beaker and start stirring carefully. Only in the presence of your lab assistant, carefully pour one sample of concentrated sulfuric acid (1 cm^3) onto the solid. Using pipettes add 1.6 cm^3 of water and 4 cm^3 of ethanol to the reaction mixture. Then using a pipette add dropwise the content of the aldehyde solution bottle (either "aldehyde 1" or "aldehyde 2", each contains 1.00 mmol of the aldehyde). Bright precipitate starts forming at once. Continue stirring for 10 min, then add 10 cm^3 of water and stir for another 3 min.

Separation and purification of the product

Using scissors carefully cut out a filter paper circle, *ca.* 1 cm bigger in diameter than that of the glass filter. Wet the filter circle with water, and carefully put it on the filtering surface. The paper filter should fit evenly and tightly. If you fail to cut out an even circle, take a new filter from the table of common use and repeat cutting out. Assemble apparatus. Remove the stirring bar from the beaker using the spatula and transfer the reaction product onto the filter. Turn on the water-jet pump and filter out the precipitate. Put a little amount of water in the beaker and transfer the leftover product onto the filter. Wash the solid on the filter with water until the pH of the drops coming out the funnel are neutral. Then wash the solid twice with ethanol using no more than 3 cm^3 each time. (Note: Hydrazone is slightly soluble in ethanol.)

Dry out the solid on the filter with working water-jet pump, loosening and squeezing the product with a glass rod from time to time. After ca. 20 - 30 min transfer carefully the dried powder into the self-made filter paper box for the final drying in the air. Put the box with the product in a safe place (e.g. on the shelf). Turn off the water-jet pump when you do not use it!

As soon as your products seem dry, we advise you weigh them to avoid queuing at the balances. To collect the products, use the plastic tubes with your student code. Fill in the answer box below.

Note: The products you synthesized will be further re-examined by lab staff.

Repeat the above procedures with the other aldehyde.

Plastic tube **1**	Plastic tube **2**
Mass of empty tube _____ mg	Mass of empty tube _____ mg
Mass of tube with product_____ mg	Mass of tube with product _____ mg
Mass of product _____ mg	Mass of product _____ mg

Tasks:

1.1 Write down the structures of 2,4-dinitrophenylhydrazine and both products.

1.2 What kind of stereoisomerism (if any) is possible for these hydrazones? Tick the appropriate box.

❑ R/S ❑ E/Z ❑ threo/erythro ❑ manno/gluco ❑ D/L

1.3 What is the role of sulfuric acid in 2,4-dinitrophenylhydrazone formation? Tick the appropriate box.

❑ stoichiometric reagent ❑ catalyst ❑ reducing agent ❑ oxidizing agent

1.4 How would the rate of the reaction change, if the synthesis is carried out in neutral medium? Tick the appropriate box.

❑ highly increase ❑ slightly increase

❑ no change ❑ the reaction would proceed very slow

1.5 How would the rate of the reaction change, if it is carried out in alkaline medium? Tick the appropriate box.

❑ highly increase ❑ slightly increase

❑ no change ❑ the reaction would not proceed

Characterization

Place small amount ("on the tip of a spatula") of each product in an individual 25 cm^3 beaker. Add 10 cm^3 of acetone to each beaker. The best results will be obtained if the colours and their intensities in each beaker are similarly yellow. Pour 5 cm^3 of $NaHCO_3$ solution into each beaker. Stir the resulting mixtures with the glass rod using different ends.

1.6 Record your observations of the solutions colour change. Tick the appropriate box.

- ❑ The colour does not change in either beaker.
- ❑ The colour changes significantly in both beakers.
- ❑ The colour changes significantly only in one beaker.

Add 2 cm^3 of NaOH solution to each of the resultant mixtures from the question **1.6**. Stir the reaction mixtures with the glass rod.

1.7 Record your observations of the solutions colour change in the box.

- ❑ The colour does not change in either beaker.
- ❑ The colour changes significantly in both beakers.
- ❑ The colour changes significantly only in one beaker.

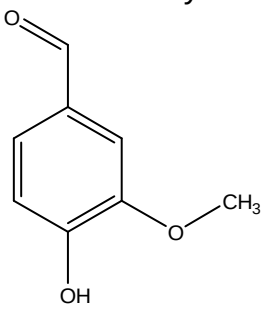
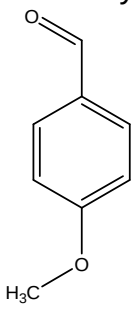
1.8 What structural features of your products explain the colour change in the reaction with $NaHCO_3$? Tick the appropriate box.

- ❑ the presence of MeO group at position 4 in the benzene ring;
- ❑ the presence of MeO group at position 3 in the benzene ring;
- ❑ the presence of the OH group at position 4 in the benzene ring;
- ❑ the presence of both MeO and OH groups.

1.9 Which of the listed processes is responsible for the colour change observed in the reaction of 2,4-dinitrophenylhydrazones with aqueous NaOH? Tick the appropriate box.

- ❑ alkaline hydrolysis
- ❑ dehydration
- ❑ hydration
- ❑ deprotonation
- ❑ dehydrogenation

1.10 Draw the structures of the main organic species present in each test reaction medium in the answer boxes below.

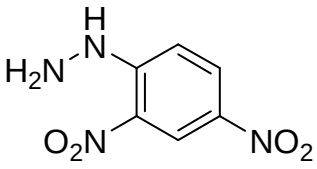
Initial aldehyde:	Initial aldehyde:
	
$NaHCO_3$	$NaHCO_3$
NaOH	NaOH

1.11 Put the numbers **1** or **2** under each structure. Calculate the percent yields of both hydrazones

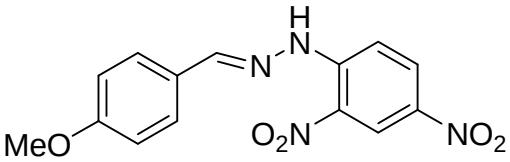
———————

SOLUTION

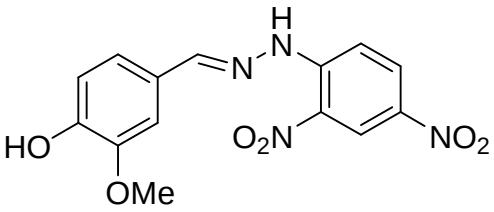
1.1 2,4-dinitrophenylhydrazine



Product 1:



Product 2:



1.2 ☑ E/Z

1.3 ☑ catalyst

1.4 ☑ the reaction would proceed very slow

1.5 ☑ the reaction would not proceed

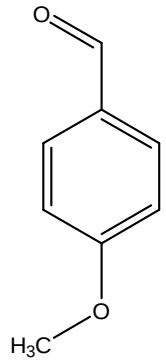
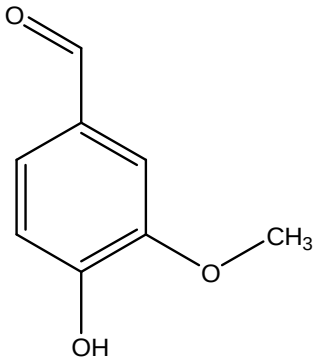
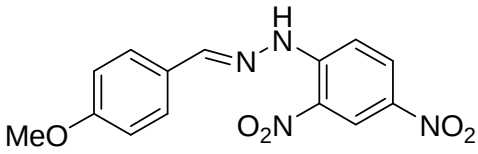
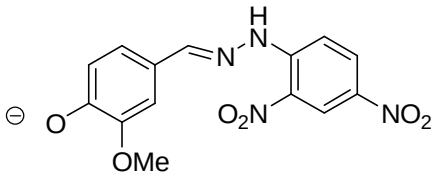
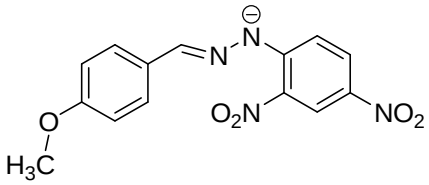
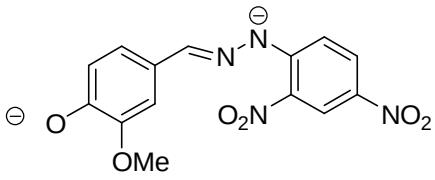
1.6 ☑ The colour changes significantly only in one beaker.

1.7 ☑ The colour changes significantly in both beakers.

1.8 ☑ the presence of the OH group at position 4 in the benzene ring;

1.9 ☑ deprotonation

1.10

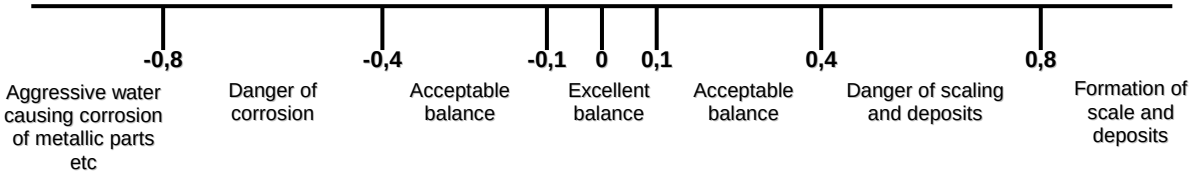
<table>
<tr><td>Initial aldehyde:
</td><td>Initial aldehyde:
</td></tr>
<tr><td>Product 1 in $NaHCO_3$
</td><td>Product 2 in $NaHCO_3$
</td></tr>
<tr><td>Product 1 in NaOH
</td><td>Product 2 in NaOH
</td></tr>
</table>

PROBLEM 2 (Practical)

Determination of the Langelier Saturation Index of a pool water

The Langelier Saturation Index (LI) is a measure of swimming pool water corrosivity as well as its ability to dissolve or deposit calcium carbonate. If LI is approximately zero, the water is considered “balanced”. If the index LI is a positive number, the water tends to deposit calcium carbonate and is scale-forming. If the index LI is a negative number, the water is corrosive and dissolves calcium carbonate. The LI is a combination of the physical values factors taken from Table 1 and can be calculated by the formula:

LI = pH + FT + FD + FA – FTDS



pH : pH value

FT : Temperature factor

FD : Calcium hardness (CH) factor

FA : Total alkalinity (TA) factor

FTDS: Total dissolved solids (TDS) factor

Table 2.1 Values and corresponding factors

Temperature, °C	FT	Calcium hardness (CH), mg dm^{-3} $CaCO_3$	FD	Total alkalinity (TA), mg dm^{3} $CaCO_3$	FA	Total dissolved solids (TDS), mg dm^{-3} NaCl	FTDS
0	0.0	5	0.3	5	0.7	0	12.0
3	0.1	25	1.0	25	1.4	-	-
8	0.2	50	1.3	50	1.7	1000	12.1
12	0.3	75	1.5	75	1.9	-	-
16	0.4	100	1.6	100	2.0	2000	12.2
19	0.5	150	1.8	125	2.1	-	-
24	0.6	200	1.9	150	2.2	3000	12.25
29	0.7	250	2.0	200	2.3	-	-

Table 2.1 continued

34	0.8	300	2.1	300	2.5	4000	12.3
41	0.9	400	2.2	400	2.6	-	-
53	1.0	600	2.35	800	2.9	5000	12.35
-	-	800	2.5	1000	3.0	-	-
-	-	1000	2.6	-	-	6000	12.4

In this task you will have to determine the LI value of a given water sample. Note that hardness is expressed as the equivalent to the concentration of $CaCO_3$ (expressed in mg dm^{-3}). Total alkalinity, being the acid equivalent to the total amount of carbonate and hydrogen carbonate, can also be expressed in mg dm^{-3} of $CaCO_3$, whereas TDS is recalculated as concentration of NaCl (mg dm^3).

Chemicals

- EDTA, standard aqueous solution, c = 0.0443 mol dm^{-3},
- HCl, standard aqueous solution, c = 0.0535 mol dm^{-3},
- Methyl orange, 0.1% in water,
- Murexide, indicator, solid mixture with NaCl (1 : 250 by mass),
- Sample of water.

Procedures

Calcium hardness is determined by complexometric titration with EDTA (Na_2H_2Y). This is performed in a strongly alkaline medium to mask magnesium (large amounts of Mg^{2+} interfere due to the co-precipitation of calcium with $Mg(OH)_2$; moreover, the complexometric indicator is also adsorbed on $Mg(OH)_2$, which impairs the observation of its colour change). When the alkali is added, titration should be carried out immediately to avoid the deposition of $CaCO_3$.

2.1 Write down equation of the reaction occurring during titration with Na_2H_2Y.

Procedure for determination of calcium

a) Put the standard solution of EDTA (precise exact concentration c = 0.0443 mol dm^{-3}) in the burette.

b) Pipette a 20 cm^3 aliquot of the water sample into an Erlenmeyer flask.

c) Add 3 cm^3 of NaOH solution (c = 2 mol dm^{-3}) with the 10 cm^3 measuring cylinder.

d) Add murexide indicator with spatula to obtain noticeably pink solution.

e) Within few minutes titrate the mixture with EDTA solution until the indicator colour changes from pink to purple.

2.2 Fill in the table 2.2.

Table 2.2

Volume of EDTA solution	Titration No			
Initial reading of the burette, cm^3				
Final reading of the burette, cm^3				
Consumed volume, cm^3				

Accepted volume, cm^3:

2.3 Calculate the hardness of the water sample in mg dm^{-3} of $CaCO_3$. Write down the result in Table 2.4 (see question 2.11).

Measurement of pH

Locate a pH meter in the lab (or ask your lab assistant).

a) Place about 70 -- 90 cm^3 of the water sample into a clean Erlenmeyer flask.

b) Remove the protective cap from the pH-meter (keep the cap standing, since there is solution in it).

c) Rinse the electrode with distilled water using a plastic wash bottle.

d) Turn the pH meter on by sliding the ON/OFF switch.

e) Immerse the electrode in the solution to be tested and stir gently by swirling the flask.

f) Place the flask on the table and wait until the reading stabilizes (not more than 1 min).

g) Read and record the pH value.

h) Switch the pH meter off, rinse the electrode with distilled water and place the protective cap back.

2.4 Write down the pH value in Table 2.4 (see question 2.11).

2.5 Which form of carbonic acid predominates in your water sample?

Confirm your choice with calculation and tick one box.

❑ Carbonate ❑ Hydrogen carbonate ❑ Carbonic acid

Note: The dissociation constants of carbonic acid are as follows:

$K_1 = 4.5 \cdot 10^{-7}$;

$K_2 = 4.8 \cdot 10^{-11}$.

2.6 Write down the ionic equation of the predominant reaction of titration of the water sample with HCl solution.

Determination of the total alkalinity

To obtain the value of the total alkalinity the water sample should be titrated to H_2CO_3. An acid-base indicator used is methyl orange, which starts changing its colour from yellow to orange at pH of about 4.5.

a) Rinse the burette with distilled water and fill it with the standard HCl solution (exact concentration of HCl is 0.0535 mol dm^{-3}).

b) Pipette a 50.0 cm^3 aliquot of water sample into an Erlenmeyer flask and add 3 drops of methyl orange solution.

c) If the sample is orange prior to addition of the acid the total alkalinity is zero. If the solution is yellow titrate it with the standard acid solution until the first noticeable colour change towards orange is observed. Record the volume of the titrant used.

2.7 Fill in the Table 2.3.

Table 2.3

Volume of the standard HCl solution	Titration No			
Initial reading of the burette, cm^3				
Final reading of the burette, cm^3				
Consumed volume, cm^3				
Accepted volume, cm^3 _____				

2.8 Calculate the total alkalinity (in mg dm^{-3} $CaCO_3$). Write down the result in Table 2.4 (see question 2.11).

2.9 Temperature measurement

Read the thermometer located at the table of common use and write down the value into Table 2.4 (see question 2.11).

2.10 TDS determination in the water sample with the test strip.

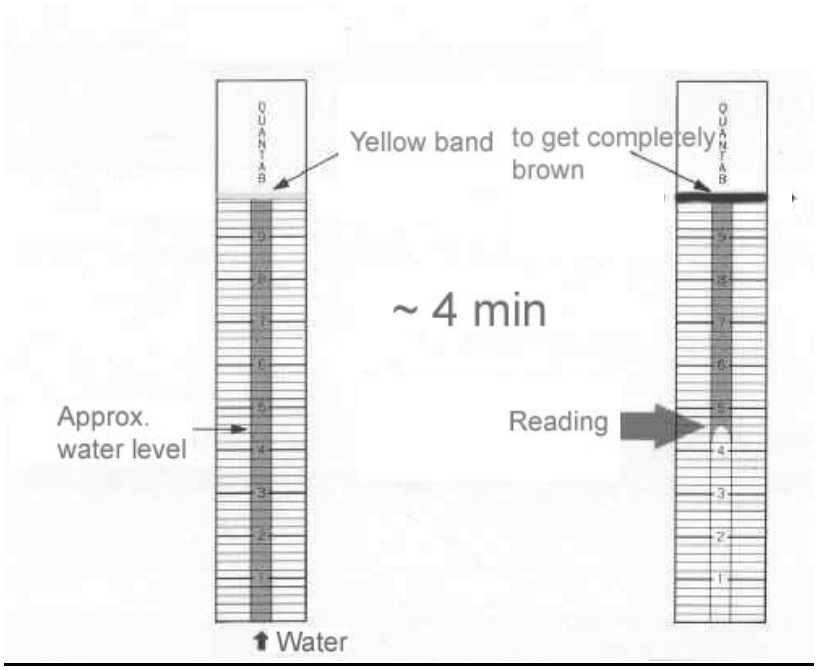
a) Fill a beaker with the water sample to a level of about 3 cm of height. Immerse the strip into water; be sure that the yellow band on the top of the strip does not touch the liquid.

b) Wait for 3 - 4 minutes until the yellow band turns completely brown. Take the reading as shown in the picture hereunder. Give it to one decimal digit.

c) Report the reading.

d) Find your TDS concentration as that of NaCl in mg dm^{-3} in the table to the right of the picture.

e) Write down the concentration of NaCl in Table 2.4 (see question 2.11).



Reading	NaCl conc., mg dm^{-3}
1.4	360
1.6	370
1.8	420
2.0	430
2.2	470
2.4	530
2.6	590
2.8	660
3.0	730
3.2	800
3.4	880
3.6	960
3.8	1050
4.0	1140
4.2	1240
4.4	1340
4.6	1450
4.8	1570
5.0	1700

2.11 Fill in all the blank boxes in the Table 2.4. Calculate LI and write down the result in Table 2.4. Take the values of the factors to the accuracy of two decimal digits.

Table 2.4. Calculation of LI of the water sample

Water sample Number _____					
CH, mg dm^{-3} $CaCO_3$	TA, mg dm^{-3} $CaCO_3$	*t*, °C	pH	TDS, mg dm^{-3} NaCl	**LI**
FD	FA	FT		FTDS	

Theoretical questions. Water balance correction.

If LI significantly deviates from zero, it is needed to be adjusted to zero.

Imagine you are given a sample of pool water analyzed as you have done above. The results of the analysis are as follows: CH = 550 mg dm^{-3}, FD = 2.31, TA = 180 mg dm^{-3}, FA = 2.26, t = 24 ˚C, FT = 0.6; TDS = 1000 mg dm^{-3}, FTDS = 12.1, pH = 7.9, LI = 0.97. The pool serviceman added 10 cm^3 of 0.0100 mol dm^{-3} solutions of reagents ($NaHCO_3$, NaOH, $NaHSO_4$, $CaCl_2$, EDTA (disodium salt dihydrate) and HCl) to 200 cm^3 of different pool water samples (one reagent for one sample).

2.12 Decide whether $CaSO_4$ is deposited upon addition of $NaHSO_4$.

Yes ❑ No ❑

Tick one box and confirm your choice with calculation.

Note: $CaSO_4$ solubility product is $5 \cdot 10^{-5}$. Assume that no precipitate of $CaCO_3$ is formed upon addition of any of the above reagents.

2.13 Fill in the hereunder table 2.5 by showing the trends of changes resulting from addition of each reagent to this particular water sample (use "+" if the factor increases, "–" if it decreases, and "0" if it does not change).

Table 2.5

Reagent	pH	FA	FD	FTDS	LI
$NaHCO_3$					
NaOH					
$NaHSO_4$					
$CaCl_2$					
Na_2H_2Y					
HCl					

SOLUTION

2.1 $H_2Y^{2-} + Ca^{2+} = CaY^{2-} + 2\ H^+$

Reactions with other forms of EDTA are also acceptable.

2.5 We observe pH ~8 $\Rightarrow$ this is carbonic acid - hydrogen carbonate buffer, then:

$$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{K_1}{[H^+]} = 45$$

i.e. ~ 98 % of hydrogen carbonate

☐ Carbonate ☑ Hydrogen carbonate ☐ Carbonic acid

2.6 $HCO_3^- + H^+ = H_2CO_3$ (or $H_2O + CO_2$)

2.12 $[Ca^{2+}] = \frac{V_{EDTA} \times c_{EDTA}}{20} \frac{200}{200+10} = \frac{2.2 \times 0.05}{\frac{20 \times 200}{210}} = 0.00524$ mol dm^{-3}

When $NaHSO_4$ is added, $[SO_4^{2-}] = \frac{0.01 \times 10}{(200+10)} = 0.000476$ mol dm^{-3}

Then $[Ca^{2+}]\ [SO_4^{2-}] = 0.00524 \times 0.000476 = 2.5 \cdot 10^{-6} < K_{sp}$

$\Rightarrow$ no precipitate of $CaSO_4$ is formed.

Your answer (tick one) Yes ☐ No ☑

2.13

Reagent	pH	FA	FD	FTDS	LI
$NaHCO_3$	+	+	0	+	+
NaOH	+	+	0	+	+
$NaHSO_4$	–	–	0	+	–
$CaCl_2$	0	0	+	+	+
Na_2H_2Y	–	–	–	+	–
HCl	–	–	0	0	–

PROBLEM 3 (Practical)

Determination of molecular mass by viscometry

Viscosity coefficient is a measure of fluid resistance to flow. It can be determined by measuring the rate of liquid flow through a thin capillary. Polymer solution viscosity grows with increasing concentration. At constant concentration, stronger solvent-polymer interactions result in more expanded polymer coils and, therefore, in higher viscosity. Provided the density of the diluted solution of a polymer is equal to that of the solvent, the reduced viscosity η_{red} of the polymer solution with concentration c (g cm^{-3}) is defined as follows:

$$\eta_{\text{red}} = \frac{t - t_0}{t_0 c} \quad \left[\text{cm}^3\ \text{g}^{-1}\right],$$

where t and t_0 are the flow times of the solution and pure solvent, respectively.

Reduced viscosity for dilute polymer solutions depends on concentration as follows:

$$\eta_{red}(c) = [\eta] + k c\ ,$$

with k, a parameter and [η], intrinsic viscosity (cm^3 g^{-1}). The intrinsic viscosity *[η]* is determined by extrapolation of the reduced viscosity to zero polymer concentration. In general, the intrinsic viscosity is related to the molecular mass M of the polymer according to the Mark-Kuhn-Houwink equation:

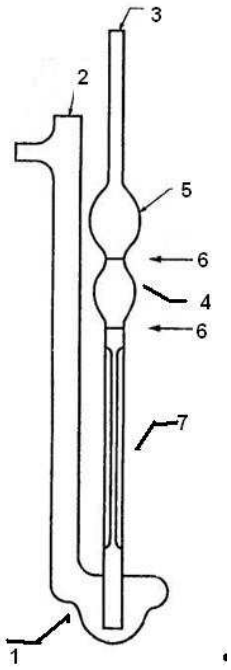
$$[\eta] = K\, M^{\alpha}\ ,$$

where K and α are the constants for a particular solvent–polymer pair at a certain temperature. Thus, M can be derived from the Mark-Kuhn-Houwink equation using experimentally determined *[η]* and reference data for K and α.

How to work with viscometer

a) Mount the viscometer (see the picture below) attached so that its tubing (3) is vertical, and the collection vessel (1) stands on the lab stand basement. Adjust the fixing clamp as low as possible.

b) Put 10 cm^3 of the liquid to be analyzed into the collection vessel (1) through the tubing (2) using a pipette.



1 – collection vessel
2 – supplementary tubing
3 – supplementary tubing
4 – measurement vessel
5 – collection vessel
6 – the match marks
7 - capillary

c) Place the pipette filler or rubber bulb on top of the tubing (3) and suck the liquid into the measurement vessel (4) so that the liquid is drawn into the collection vessel (5). When sucking the liquid, avoid the air bubbles in the capillary (7) and the vessels (4, 5), as these can cause significant experimental errors. The liquid meniscus should be about 10 mm above the upper mark (6).

d) Zero the stopwatch, and remove the pipette filler or bulb out of the tube (3). The liquid starts flowing down to the collection vessel (1).

e) Measure the flow time: start the stopwatch when the liquid meniscus passes the upper match mark (6) and stop the stopwatch when the liquid meniscus passes the lower match mark (6).

ATTENTION: Handle the viscometer with great care!
There will be no replacement if you have broken your viscometer!
If you break your viscometer tell the lab assistant. You may then attempt to do the experiment using the 25 mL pipette and beaker in place of viscometer.

Clean the viscometer three times with tap water and once with distilled water before you pass over to a new polymer sample. To do this, first wash it with tap water, and then rinse with distilled water. There is no need to wash it with the polymer solution, the error can occur but it is negligible.

You are NOT requested to fill in all table cells in the Answer Boxes. Perform as many measurements as you prefer for accurate averaging.

Chemicals

- Poly(vinyl) alcohol, 40 cm^3 each, 5 vials

Procedure

You are provided with a set of aqueous solutions of polymers (0.01 g cm^{-3}, stock solutions). Three of P1-P4 are solutions of poly(vinyl alcohol), whereas the fourth one is that of a partially hydrolyzed poly(vinyl acetate) containing *ca*. 10 % of non-hydrolyzed units. It is unknown which of the P1 – P4 solutions is partially hydrolyzed poly(vinyl acetate). Molecular masses of the polymers P1 – P4 are given in the Table.

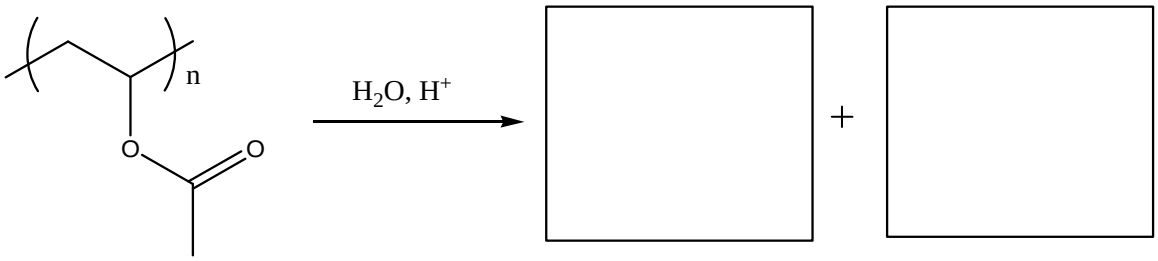
Approximate molecular mass	Sample code
26650	P2
50850	P1
65300	P4
91900	P3

Sample X is poly(vinyl alcohol) of an unknown molecular mass.

In this task you will have to identify which of P1 – P4 is the solution of partially hydrolyzed poly(vinyl acetate) and determine the molecular mass of polymer X.

3.1 Write down the reaction scheme of poly(vinyl alcohol) preparation by hydrolysis of poly(vinyl acetate).

Reaction scheme:



3.2 Choose (tick appropriate box) which polymer shows the stronger interaction with water and compare the viscosities of aqueous solutions of fully and partially hydrolyzed poly(vinyl acetates). Assume that the concentration of the solutions and the molecular masses of the polymers are the same.

Poly(vinyl alcohol)	❑
Partially hydrolyzed poly(vinyl acetate)	❑

Compare the viscosities:

η (poly(vinyl alcohol) _____ η (partially hydrolyzed poly(vinyl acetate)

(put either <. >, or ≈)

3.3 Measure the flow time of the pure solvent (distilled water). You are not requested to fill all the boxes in the answer sheet.

3.4 Measure the flow times of the stock solutions of P1 – P4, and that of X. Calculate the reduced viscosities. You are NOT requested to fill in all table cells in the Answer Boxes. Perform as many measurements as you prefer for accurate averaging.

3.5 Encircle the solution out of P1, P2, P3, P4 which is the sample of partially hydrolyzed poly(vinyl acetate). Hint: Take into account the given molecular masses of the polymers P1 – P4.

Do not use this polymer in the next part of the experiment.

3.6 To determine the parameters of the Mark-Kuhn-Houwink equation and calculate the unknown molecular mass of X choose and encircle two most appropriate solutions of poly(vinyl alcohol) with different molecular masses. Assume that the absolute error of intrinsic viscosity determination does not depend on the sample molar mass.

3.7 Using appropriate measuring glassware to prepare the solutions, measure the flow time of a number of diluted solutions of three poly(vinyl alcohol) samples: that of an unknown molecular mass (X), and the pair of poly(vinyl alcohols) chosen in 3.6, and

calculate the corresponding reduced viscosities. When calculating the diluted solutions concentration, assume that density of the polymer solutions is equal to that of water. Determine the intrinsic viscosities for each of the examined samples. Submit the graph paper with your plots together with the booklet. **Note:** if you would like to plot the data referring to different samples on the same plot, make sure you use clearly distinguishable symbols for each dataset. You are NOT requested to fill in all table cells in the answer booklet.

Summary of experimental results (only fill in the measured values)

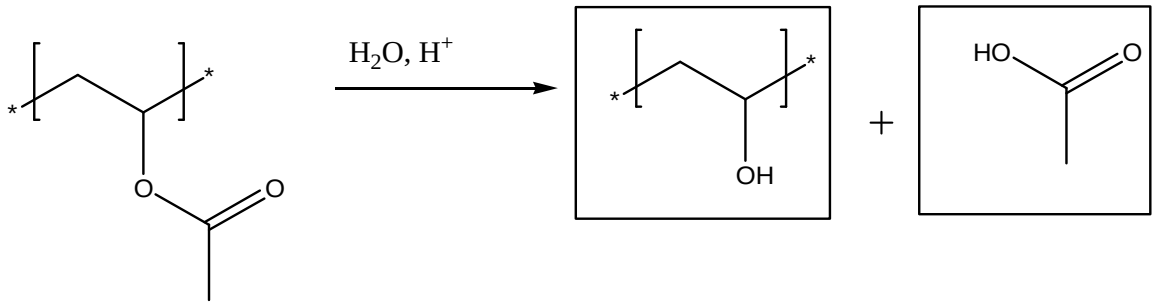
Sample	P__	P__	X
Concentration (c), g cm^{-3}:	0.01	0.01	0.01
Reduced viscosity (η_{red}), $cm^3\,g^{-1}$			
c (1st dilution), g cm^{-3}:			
η_{red}, $cm^3\,g^{-1}$			
c (2nd dilution), g cm^{-3}:			
η_{red}, $cm^3\,g^{-1}$			
c (3rd dilution), g cm^{-3}:			
η_{red}, $cm^3\,g^{-1}$			
c (4th dilution), g cm^{-3}:			
η_{red}, $cm^3\,g^{-1}$			
c (5th dilution), g cm^{-3}:			
η_{red}, $cm^3\,g^{-1}$			

3.8 Write down the form of equation you would use to determine K and α.
Derive the *K* and α values for the aqueous solution of poly(vinyl alcohol).

3.9 By using the obtained *K* and α values, as well as the intrinsic viscosity of the X solution, calculate the molecular mass of the polymer X. If you have failed to determine *K* and α, use $K = 0.1\ cm^3\,g^{-1}$ and $\alpha = 0.5$.

SOLUTION

3.1



3.2

Poly(vinyl alcohol) ☑

η (poly(vinyl alcohol) > η (partially hydrolyzed poly(vinyl acetate)

3.8 $\log[\eta] = \log K + \alpha \log M$

3.9 Sample calculation:

$23.7 = 0.1 \times M^{0.5} \Rightarrow 237 = M^{0.5}$

$M = 237^2 = 56169 \approx 56200$