State of Israel
Ministry of Education
Exam type:
Bagrut for high schools
Exam date: Summer 2011
Exam number: 037202
Attachment: Formulas and data for chemistry
English Translation (3)

מדינת ישראל
משרד החינוך
סוג הבחינה:
בגרות לבתי ספר על־יסודיים
מועד הבחינה: קיץ תשע״א, 2011
מספר השאלון: 037202
נספח: נוסחאות ונתונים בכימיה
תרגום לאנגלית (3)

Chemistry

Hashlama from 3 to 5 points
for students taking a written test in
Research Laboratory
and students who took Lab for half a point

Instructions for examinees

א. Duration of the exam: Two hours.

ב. Exam structure and breakdown of points:
This test has two parts.

Part I	$(1\times 33\frac{1}{3})$	$33\frac{1}{3}$	points
Part II	$(2\times 33\frac{1}{3})$	$66\frac{2}{3}$	points
	Total	100	points

ג. Material that may be used during the exam:
(1) A calculator (graphing calculators are permitted).
(2) A Hebrew-foreign language/foreign language-Hebrew dictionary.

ד. Special instructions:
On the outside cover of your answer booklet, list the topic or topics in Part II on which you chose to answer questions.

Write only in the answer booklet. Write whatever you wish to write as a draft (calculations, notes, etc.) on separate pages in the booklet and write "טיוטה" at the top of each of these pages. If you write any sort of notes or calculations outside the answer booklet, your exam may be disqualified!

Good Luck!

/ Continued on the next page /

כ י מ י ה

השלמה מ־3 ל־5 יחידות לימוד
לתלמידים הנבחנים בכתב במעבדת חקר
ולתלמידים שלומדים חצי יחידת מעבדה

הוראות לנבחן

א. משך הבחינה: שעתיים.

ב. מבנה השאלון ומפתח ההערכה:
בשאלון זה שני פרקים.

פרק ראשון	$(33\frac{1}{3}\times 1)$ —	$33\frac{1}{3}$	נקודות
פרק שני	$(33\frac{1}{3}\times 2)$ —	$66\frac{2}{3}$	נקודות
	סה״כ —	100	נקודות

ג. חומר עזר מותר בשימוש:
(1) מחשבון (כולל מחשבון גרפי).
(2) מילון עברי-לועזי/לועזי-עברי.

ד. הוראות מיוחדות:
רשום על הצד החיצוני של מחברת הבחינה את הנושא או הנושאים שענית עליהם בפרק השני.

כתוב במחברת הבחינה בלבד, בעמודים נפרדים, כל מה שברצונך לכתוב כטיוטה (ראשי פרקים, חישובים וכדומה). רשום ״טיוטה״ בראש כל עמוד טיוטה. רישום טיוטות כלשהן על דפים שמחוץ למחברת הבחינה עלול לגרום לפסילת הבחינה!

בהצלחה!

/המשך מעבר לדף/

Questions

Note: Make sure that all equations are balanced and that the correct units are indicated.

Part One ($33\frac{1}{3}$ points)

Required Topic — Kinetics and Thermodynamics

Answer one of the questions 1-2.

1. Scientists are developing a new method for using solar energy to produce carbon monoxide, $CO_{(g)}$, which can be used as fuel. In this method, giant mirrors are used to concentrate the sun's rays onto a cell that contains carbon dioxide, $CO_{2(g)}$, and titanium, $Ti_{(s)}$. The temperature in the cell increases to 1173 K and then Reaction (1) occurs. Carbon monoxide, $CO_{(g)}$, is obtained via Reaction (1).

(1) $2CO_{2(g)} + Ti_{(s)} \longrightarrow 2CO_{(g)} + TiO_{2(s)} \qquad \Delta H^o = -379\text{kJ}$

Standard entropy values, S°, for the reactants and products of Reaction (1) are presented in the table below.

Substance	$CO_{2(g)}$	$CO_{(g)}$	$TiO_{2(s)}$	$Ti_{(s)}$
$S^o\left(\frac{J}{K\cdot mol}\right)$	214	198	50	31

א. i Calculate the change in the entropy of the system, $\Delta S°_{system}$, for Reaction (1). Show detailed calculations.

ii Determine whether Reaction (1) is spontaneous under standard conditions at 298 K. Show detailed calculations and explain.

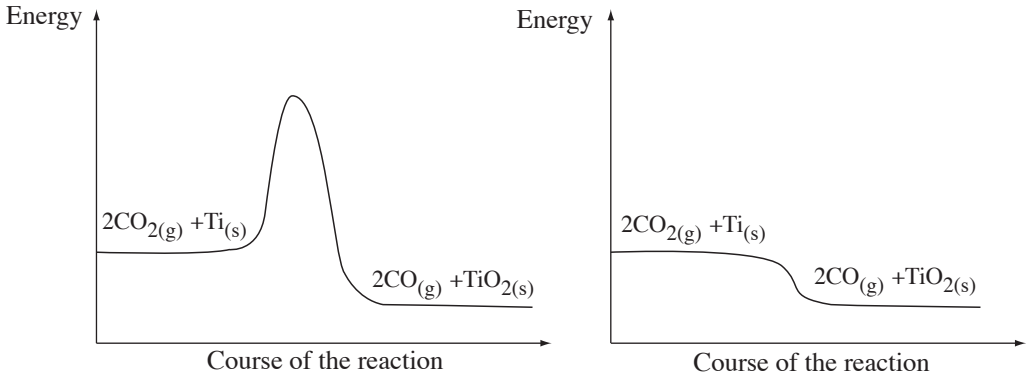
iii Two statements, (a) and (b), are presented below. Which of the statements correctly explains why Reaction (1) is carried out at a temperature of 1173 K and not at a temperature of 298 K?

(a) The activation energy of Reaction (1) at 1173 K is lower than the activation energy of this reaction at 298 K.

(b) At 1173 K, more particles of the reactants in Reaction (1) have sufficient energy to produce activated complexes [תצמידים משופעלים].

(Note: This question continues on the next page.) /Continued on page 3/

ב. Which of the graphs I-II below correctly describes the changes in energy over the course of Reaction (1)? Explain why you rejected the other graph.



I **II**

Methanol, $CH_3OH_{(\ell)}$, can also be used as fuel. $CO_{(g)}$ can be used to produce $CH_3OH_{(\ell)}$, as described in Reaction (2):

(2) $CO_{(g)} + 2H_{2(g)} \xrightleftharpoons{Cu_{(s)}} CH_3OH_{(\ell)} \qquad \Delta H^o = -128.5kJ$

Reaction (2) proceeds spontaneously at 323 K. Reaction (2) is carried out at 323 K in the presence of a catalyst — copper, $Cu_{(s)}$.

ג. i Explain why the reaction is carried out in the presence of a catalyst.

ii Sketch two curves on the same system of axes that provide a schematic description of the change in energy over the course of Reaction (2):
First curve — for the reaction without a catalyst.
Second curve — for the reaction in the presence of the catalyst $Cu_{(s)}$.

ד. Someone proposed carrying out Reaction (2) at a temperature of 333 K.

i Determine whether the rate of the reaction at 333 K will be greater than, less than or equal to the rate of the reaction at 323 K. Explain.

ii Determine whether the value of the equilibrium constant at 333 K will be greater than, smaller than or equal to the value of the equilibrium constant at 323 K. Explain.

/Continued on page 4/

2. Limestone — calcium carbonate, $CaCO_{3(s)}$ — is used to make statues, among other things.

Acid rain corrodes statues made of limestone.

When limestone comes into contact with acid rain, Reaction (1) occurs.

(1) $CaCO_{3(s)} + 2H_3O^+_{(aq)} \rightarrow Ca^{2+}_{(aq)} + 3H_2O_{(\ell)} + CO_{2(g)} \quad \Delta H^o = -15.5kJ$

א. i The standard entropy of water, $H_2O_{(\ell)}$, is less than the standard entropy of carbon dioxide, $CO_{2(g)}$. Explain why.

ii Determine whether the entropy of the system increases, decreases or remains the same over the course of Reaction (1). Explain.

iii Determine whether there is a range of temperatures within which Reaction (1) does not proceed spontaneously. Explain.

Three experiments were carried out: I, II and III. Reaction (1) occurred in each of the experiments. In Experiment I, 0.2 grams of limestone granules were added to 30 milliliters of a hydrogen chloride solution, $HC\ell_{(aq)}$, with a concentration of 1 M, at a temperature of 25ºC.

The results of Experiment I are presented in the table below.

Time from the start of the experiment (minutes)	0	1	2	3
Number of mols of $CO_{2(g)}$ obtained in Experiment I	0	0.0040	0.00064	0.00076

ב. i Based on the results of the experiment, determine whether the rate of the reaction is constant or variable over the course of the reaction. Explain your conclusion.

ii Explain the results of the experiment at the microscopic level.

The rate of formation of $Ca^{2+}_{(aq)}$ ions during the first minute of Experiment I was $0.0133\frac{M}{min}$.

ג. i What was the rate of the disappearance of $H_3O^+_{(aq)}$ ions during the first minute? Explain.

ii What was the rate of Reaction (1) during the first minute of Experiment I?

(Note: This question continues on the next page.)

/Continued on page 5/

ד. In Experiment II, 0.2 grams of limestone granules were added to 30 milliliters of a hydrogen chloride solution, $HC\ell_{(aq)}$, with a concentration of 0.2 M, at a temperature of 25ºC.
Determine whether the rate of the reaction during the first minute of Experiment II was greater than, less than or equal to the rate of the reaction in Experiment I. Explain.

ה. In Experiment III, a chunk of limestone (instead of granules) with a total mass of 0.2 grams was added to 30 milliliters of a hydrogen chloride solution, $HC\ell_{(aq)}$, with a concentration of 1 M, at a temperature of 25ºC.
Determine whether the rate of the reaction during the first minute of Experiment III was greater than, less than or equal to the rate of the reaction in Experiment I. Explain.

/Continued on page 6/

Part Two ($66\frac{2}{3}$ points)

This part includes seven topics (questions 3-15).
You must answer two questions (each question — $33\frac{1}{3}$ points).
Note: Students who took Research Laboratory, 1 point, must answer question 15.
On the cover of the answer booklet, write the topic or topics on which you chose to answer questions in Part Two.

First Topic — Bromine and its Compounds

3. At the Bromine Compounds factory, a solution of calcium bromide, $CaBr_{2(aq)}$, is produced from a hydrogen bromide solution, $HBr_{(aq)}$, and limestone, $CaCO_{3(s)}$, according to the reaction:

$$CaCO_{3(s)} + 2H_3O^+_{(aq)} + 2Br^-_{(aq)} \longrightarrow Ca^{2+}_{(aq)} + 2Br^-_{(aq)} + CO_{2(g)} + 3H_2O_{(\ell)}$$

א. i Which reactant — $CaCO_{3(s)}$ or $HBr_{(aq)}$ solution — do we use to calculate the percent conversion? Explain.

ii Is the percent yield of the process likely to be closer to 100% or closer to 90%? Explain.

ב. The $HBr_{(aq)}$ solution is put into the reaction container first and then the limestone is added.

i The limestone is added in small amounts. Explain why.

ii The $CO_{2(g)}$ gas that is emitted during the reaction is transferred by an absorption system that contains water. What is the goal of this measure?

ג. $CaBr_{2(aq)}$ solution is generally sold as a solution with a concentration of 52%.

i A $CaBr_{2(aq)}$ solution with a concentration of 48% is obtained in the reaction container. How is the concentration of the solution increased in the factory?

ii Present one advantage to marketing calcium bromide as a solution as opposed to marketing it as a solid.

(Note: This question continues on the next page.)

/Continued on page 7/

Aqueous solutions containing calcium bromide, $CaBr_2$, and additional substances such as zinc bromide, $ZnBr_2$, calcium chloride, $CaC\ell_2$, and sodium bromide, NaBr, are used in oil drilling.

ד. i Of the characteristics (1)-(5) listed below, indicate three characteristics that are necessary if these solutions are to be used in oil drilling.

(1) high density [צפיפות גבוהה]

(2) high level of purity [דרגת ניקיון גבוהה]

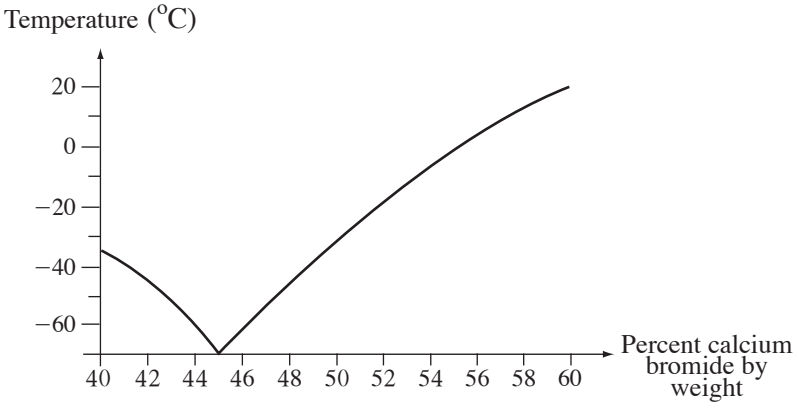
(3) chemically inert [אדישות כימית]

(4) low friction [יכולת שיתוך נמוכה]

(5) high volatility [נדיפות גבוהה]

ii Choose one of the characteristics that you indicated in Sub-item ד i and explain why it is necessary.

ה. The graph below presents the relationship between the percentage (by weight) [האחוז המשקלי] of calcium bromide in a solution and the crystallization temperature of the solution.



i One of the considerations in determining the appropriate composition of the solution to be used in oil drilling is the crystallization temperature of the solution. Explain why.

ii During the winter, the temperature in Siberia can fall to –40ºC. What does the percentage (by weight) of calcium bromide need to be in a solution used for oil drilling at a temperature of –40ºC: 48% or 52%? Explain.

/Continued on page 8/

4. At the Bromine Compounds factory, methyl bromide, $CH_3Br_{(g)}$, is produced via Reaction (1):

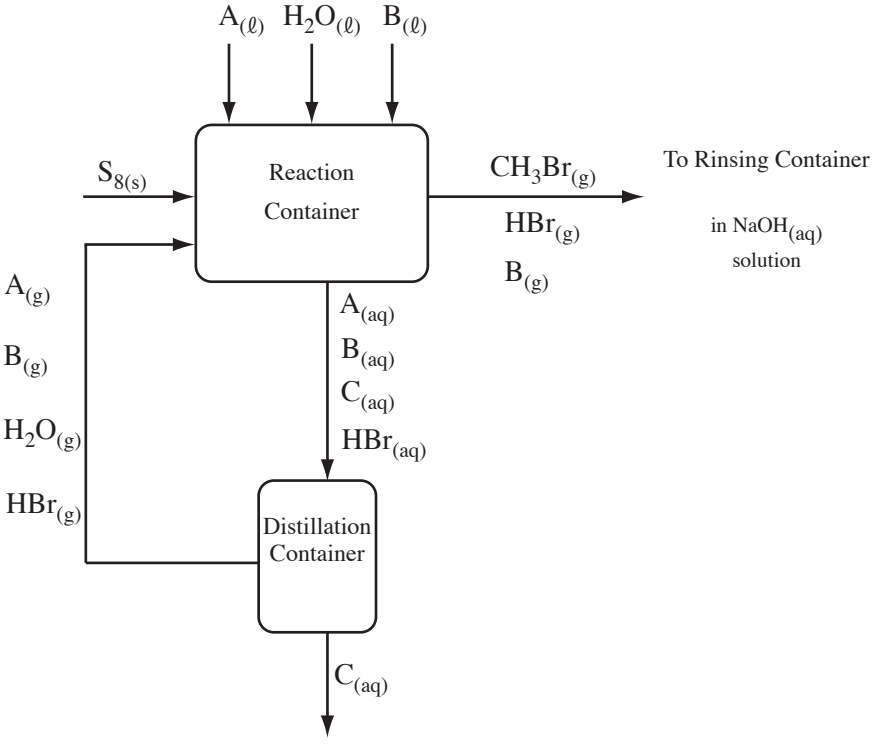
(1) $CH_3OH_{(\ell)} + H_3O^+_{(aq)} + Br^-_{(aq)} \xrightleftharpoons{H_2SO_{4(aq)}} CH_3Br_{(g)} + 2H_2O_{(\ell)}$

The two acids, $HBr_{(aq)}$ and $H_2SO_{4(aq)}$, are obtained in the reaction container from bromine, $Br_{2(\ell)}$, and sulfur, $S_{8(s)}$, via Reaction (2):

(2) $3Br_{2(\ell)} + \frac{1}{8}S_{8(s)} + 11H_2O_{(\ell)} \longrightarrow 7H_3O^+_{(aq)} + 6Br^-_{(aq)} + HSO^-_{4\,(aq)}$

א. i Producing the two acids in the reaction container is cheaper than using prepared solutions: $HBr_{(aq)}$ solution produced in the factory and $H_2SO_{4(aq)}$ solution acquired already made.
Give <u>two</u> reasons why the process by which the acids are produced in the reaction container is cheaper.

ii Part of a flow chart for the production of methyl bromide, $CH_3Br_{(g)}$, is presented below.



Identify the materials A, B and C based on the figure and Reactions (1) and (2).

(Note: This question continues on the next page.)

/Continued on page 9/

ב. The yield [ניצולת] of the process for the production of methyl bromide via Reaction (1) is 90%.

2.56 tons of $CH_3OH_{(\ell)}$ reacted with $HBr_{(aq)}$ solution.

6.498 tons of $CH_3Br_{(g)}$ were obtained.

Calculate the percent conversion [אחוז ההמרה] of this process.

Show detailed calculations.

ג. The mixture of gases coming out of the reaction container moves into the rinsing container in a solution of $NaOH_{(aq)}$.

What is the goal of this step and what is it based on?

ד. i $CH_3Br_{(g)}$ is produced in a continuous process. Give one reason for this.

ii The $CH_3Br_{(g)}$ production process is carried out in a system kept at a pressure lower than atmospheric pressure [תת-לחץ]. Explain why.

ה. Methyl bromide is a poisonous substance that is mainly used to disinfect soil. Under standard conditions [תנאי חדר], methyl bromide is a gas.

In order to carry out the disinfection process, $CH_3Br_{(g)}$ is injected into soil that is covered with sheets of plastic. After several days, the plastic is removed.

Why does the soil need to be kept covered for several days? Give two reasons.

/Continued on page 10/

Second Topic — Polymers

5. A study was conducted to learn about water-absorbing polymers that can be used in disposable diapers, among other things.

During the first part of the research process, Polymer A was prepared from Monomer (1):

(1) $CH_2 = CH - COOH$

א. Write out a structural formula for a segment of Polymer A that includes three repeating units.

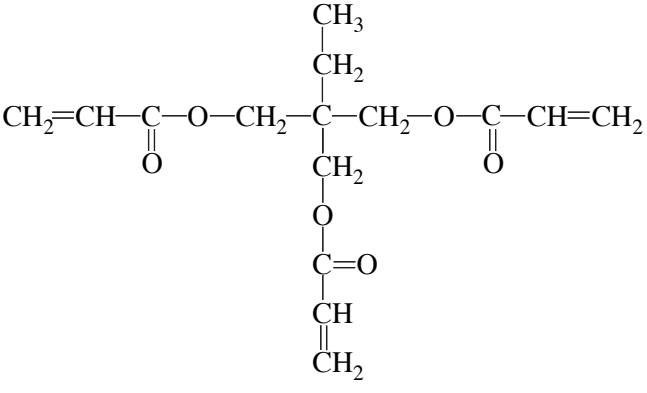
ב. Two batches of Polymer A were prepared from identical amounts of Monomer (1). The polymerization occurred in the presence of a radical initiator [יזם רדיקלי].

i When a large amount of the initiator was present, a water-soluble polymer was obtained. Explain this fact.

ii When a small amount of the initiator was present, a polymer that absorbs water, but does not dissolve in it was obtained. Explain this fact.

Later in the research process, Polymer B was prepared from Monomers (1) and (2). Below is the structural formula of Monomer (2).

(2)



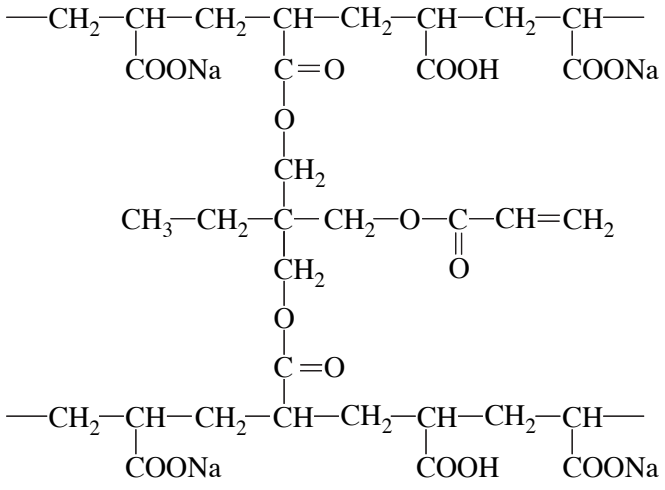
ג. i How does the structure of Polymer B differ from the structure of Polymer A?

ii Which polymer is better suited for the production of disposable diapers: the polymer whose production involved a large amount of Monomer (1) and a small amount of Monomer (2), or the polymer whose production involved a small amount of Monomer (1) and a large amount of Monomer (2)? Explain.

(Note: This question continues on the next page.)

/Continued on page 11/

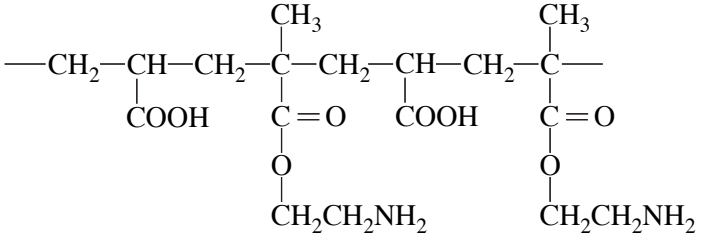
ד. Even later in the research process, Polymer C was prepared. In Polymer C, some of the side-groups are –COONa groups. A representative segment of Polymer C is shown below.



i How is it possible to get a –COONa group from a –COOH group?

ii The water-absorbing ability of Polymer C is greater than the water-absorbing ability of Polymer B. Explain why.

ה. A representative segment of an additional water-absorbing polymer, Polymer D, is presented below.



i Which method is used to produce Polymer D: condensation [דחיסה] or addition [סיפוח]? Explain.

ii Write the structural formula of each of the monomers used to produce Polymer D.

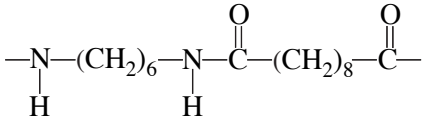
/Continued on page 12/

6. During the recycling of nylon, the polymer is broken down into monomers and additives.

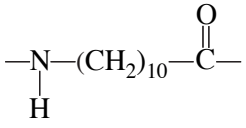
Once the monomers have been separated from the additives, they can be used to make new polymers.

Structural formulas of the repeating units of two polymers are shown below.

Nylon 6, 10, which is mainly used to make different types of brushes:

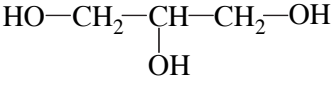


Nylon 11, which is mainly used to make the soles of sneakers:



א. i The two polymers are broken down into monomers by hydrolysis. What materials and conditions are necessary for the hydrolysis of the two polymers?

ii Write out structural formulas of the monomers obtained when Nylon 6, 10 and Nylon 11 are broken down.

ב. The cross-linked polymer A [A פולימר מוצלב] was prepared from one of the monomers obtained from the breakdown of Nylon 6, 10 and glycerol,  .

i Write out a structural formula of the monomer that reacted with glycerol.

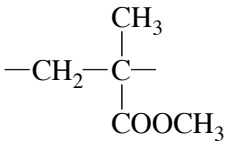
Explain why you chose this monomer.

ii Write out a structural formula for a representative segment of the cross-linked polymer A.

(Note: This question continues on the next page.)

/Continued on page 13/

Polymer B was prepared. Below is a structural formula of the repeating unit of Polymer B:



ג. The average distance between the ends of the chain of Polymer B was found to be smaller than the length of the open chain [השרשרת הפרושה] that includes the same number of repeating units. Explain why.

ד. Polymer C is obtained from the hydrolysis of Polymer B.

i Explain why Polymer B is not broken down into monomers during the hydrolysis process.

ii Write out a structural formula for the repeating unit of Polymer C.

iii The cross-linked polymer D is produced in a reaction between Polymer C and one of the monomers obtained when Nylon 6, 10 is broken down (see Sub-item א ii).

Write out a structural formula for the monomer that reacted with Polymer C. Explain why you chose this monomer.

/Continued on page 14/

Third Topic — Physical Chemistry — From the Nano Level to Microelectronics

7. One of the methods used in the electronics industry to clean glass surfaces is based on the use of electromagnetic radiation. In this method, a mercury lamp is used as a source of radiation.

   In the first phase of the process, the radiation causes molecules of oxygen in the air to break down into atoms.

   א. i Write out the valence levels [היערכות] of the electrons in a molecule of oxygen, O_2.

   ii Write out the valence levels of the electrons in an atom of oxygen, O.

   ב. In atoms of oxygen in which the electrons have been excited, electrons were found to have been promoted from the highest populated orbital [האורביטל המאוכלס הגבוה] to orbital 3p. Determine the possible electron transitions from orbital 3p to lower orbitals.

   ג. The minimal energy needed to break down one molecule of oxygen, O_2, is $8.26 \cdot 10^{-19}$ J.

   Determine whether a photon of wavelength 365 nm can break down a molecule of oxygen.

   Show detailed calculations and explain.

   ד. Under appropriate conditions, O_2^- ions can be produced.

   i An O_2^- ion is less stable than an O_2 molecule. Explain why.

   ii Determine whether the energy difference between the LUMO orbital and the HOMO orbital of an O_2^- ion is greater than, smaller than or equal to the energy difference between the LUMO orbital and the HOMO orbital of an O_2 molecule. Explain.

   ה. In the emission spectrum of a mercury lamp, lines appear at wavelengths 185 nm, 254 nm, 365 nm and 546 nm (among others).

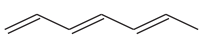
   i Determine within which range each of these wavelengths is to be found — infra-red, visible light or ultra-violet. Explain.

   ii Determine which of these wavelengths corresponds to photons with the lowest level of energy. Explain without calculations.

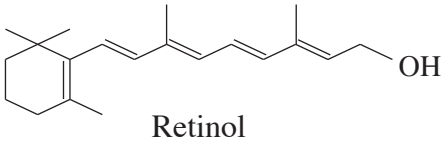
/Continued on page 15/

8. Three materials were studied in a laboratory:
   — Retinol (Vitamin A), which is essential for night vision and growth processes.
   — 1,3,5-heptatriene, which is used to produce organic compounds.
   — Lycopene, which reduces the danger of heart and vascular diseases.

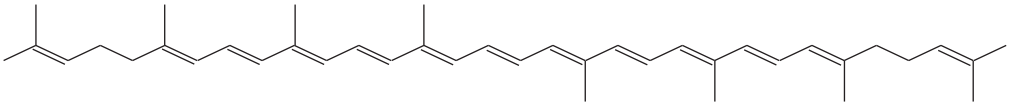
   Structural formulas of the three materials are shown below:



1,3,5-heptatriene



Retinol



Lycopene

א. i The materials are solids under room conditions. Explain why.

ii The materials are different colors: one is yellow, one is red and one is white.

Which material is yellow and which is red? Explain.

Each of the materials was dissolved in hexane, $C_6H_{14(\ell)}$, which is colorless. Three solutions were obtained: Solution (1) is yellow, Solution (2) is colorless and Solution (3) is red.

ב. Solution (2) was obtained by dissolving the white material.
Explain why Solution (2) is colorless.

ג. For each of the three solutions, the wavelengths of maximum absorption are measured.

The wavelengths are: 260 nm, 395 nm and 505 nm.

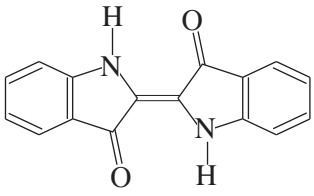
i Match each of the measured wavelengths to one of the Solutions (1), (2) and (3). Explain.

ii Calculate the energy difference between the HOMO orbital and LUMO orbital of lycopene. Show detailed calculations.

(Note: This question continues on the next page.)

/Continued on page 16/

ד. Indigo is a blue substance that is used to dye cloth.
A structural formula of indigo is shown below:



i Determine whether indigo absorbs light in the visible range.
Explain your answer at the microscopic level.

ii Material containing chlorine causes the bleaching of cloth that has been dyed with indigo.
Which change in the structure of the indigo molecules causes this loss of color? Explain.

/Continued on page 17/

Fourth Topic — Advanced Organic Chemistry

9. Methy-t-butyl ether (MTBE), $(CH_3)_3C-O-CH_{3(\ell)}$, is used as an additive in automobile fuel.

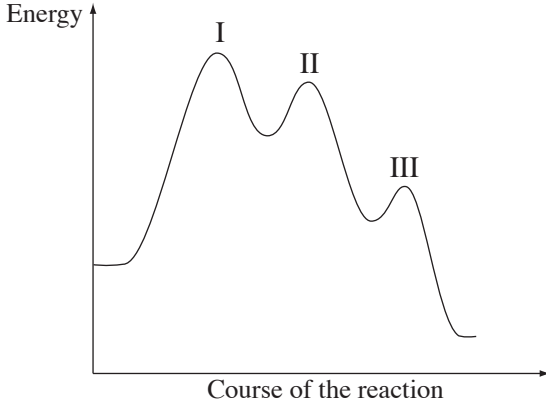
This additive improves the functioning of the vehicle's engine and reduces the emission of pollutants.

MTBE can be produced in a reaction between an appropriate alkyl bromide and methanol, $CH_3OH_{(\ell)}$, at room temperature. The methanol in this reaction serves as the solvent [ממס].

א. i Write out a structural formula for an alkyl bromide that can be used to produce MTBE.

ii Write a formula for the reaction in which MTBE is produced from the alkyl bromide (whose formula you wrote out for Sub-item א i) and methanol.

ב. The reaction that you wrote out for Sub-item א ii occurs in three stages: I, II and III. The graph below describes the energy changes over the course of the reaction.



i Write out a structural formula for the intermediate product for <u>each</u> of the stages I and II.

ii Which stage, I, II or III, determines the rate of the reaction? <u>Explain</u>.

iii Determine whether the reaction is a first-order reaction or a second-order reaction. <u>Explain</u>.

(Note: This question continues on the next page.)

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ג. The rate of the reaction does not change when it is carried out in the presence of a low concentration of methoxide ions, $CH_3O^-_{(CH_3OH)}$. Explain this fact.

ד. i With a high concentration of methoxide ions, $CH_3O^-_{(CH_3OH)}$, the main reaction is an elimination reaction that proceeds via the E2 mechanism. Explain why.

ii Write out a formula for the mechanism of this elimination reaction.

/Continued on page 19/

10. This question concerns the reactions of 2-bromopropane, $CH_3CHBrCH_{3(\ell)}$, with CH_3O^- ions and with CH_3S^- ions.

א. Which of the ions, CH_3O^- or CH_3S^-, is a stronger nucleophile? Explain.

ב. When $CH_3CHBrCH_{3(\ell)}$ reacts with $CH_3S^-_{(CH_3OH)}$ ions, the main reaction that occurs is a conversion reaction [תגובת התמרה]. For this reaction, methanol serves as a solvent.

i Write out an equation for the reaction.

ii The rate equation that corresponds to this reaction is $v = k[RBr][CH_3S^-]$.
Determine by which mechanism this reaction proceeds, S_N1 or S_N2. Explain.

iii Draw the mechanism of the reaction.

ג. In the reaction that you wrote out for Sub-item ב i, methanol was replaced by acetone, $CH_3COCH_{3(\ell)}$, as the solvent.

i Changing the solvent did not change the mechanism of the reaction, which you identified in Sub-item ב ii.
Explain why.

ii Determine whether the rate of the reaction in acetone is faster than, slower than or equal to the rate of the reaction in methanol. Explain.

ד. When $CH_3CHBrCH_{3(\ell)}$ reacts with $CH_3O^-_{(CH_3OH)}$ ions, the main reaction that occurs is an elimination reaction.
The rate equation that corresponds to this reaction is $v = k'[RBr][CH_3O^-]$.
Determine whether the rate of the reaction will increase, decrease or remain the same if the concentration of $CH_3O^-_{(CH_3OH)}$ ions is increased 3-fold [פי 3]. Explain.

ה. Explain why $CH_3CHBrCH_{3(\ell)}$ reacts with $CH_3S^-_{(CH_3OH)}$ ions in a conversion reaction, but reacts with $CH_3O^-_{(CH_3OH)}$ in an elimination reaction.

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Fifth Topic — Chemistry of Proteins and Nucleic Acids

11. In the 1970's, the researcher Sanger developed a method for determining the sequence of the nitrogenous bases in DNA. This method is based on the use of a certain type of molecule. The letter W is used to refer to these molecules.

The structure of the W molecule is similar to the structure of a nucleotide found in DNA, with one difference: the carbon-3 atom in the sugar group is bound to a hydrogen atom instead of a -OH group.

א. i Write out a structural formula for a W molecule that contains adenine.

ii The W molecule can only bind one end of a strand of DNA. Determine which end of the strand of DNA — 3' or 5' — the W molecule can bind.

Explain your answer.

ב. A group of researchers used the Sanger method to determine the sequence of nitrogenous bases in a molecule of DNA from a certain strain of bacteria. They found that the two strands of the DNA contained a total of 200,000 nitrogenous bases.

The total number of nitrogenous bases in the two strands that were cytosine bases was 70,000. How many adenine bases were there in the two strands? Explain.

A segment of a strand of a certain DNA molecule is given:

5' GGTGACCCGCATAC 3'

This section is transcribed into mRNA (messenger RNA).

ג. The transcription process is initiated by the enzyme RNA polymerase. Describe how this enzyme works.

(Note: This question continues on the next page.)

/Continued on page 21/

ד. i Write out the nucleotide sequence of the strand of mRNA that was obtained from the given DNA sequence.

ii Indicate which group is located at each of the two ends of the strand of mRNA.

iii Write out the amino acid sequence that could be obtained from the given DNA sequence, paying attention to the start codon.

ה. Below is an amino acid sequence from a section of the Ras protein:
Val – Val – Val – Gly – Ala

In a molecule of mRNA, in the section that codes for this sequence, the codon that corresponds to glycine is GGC.

One nitrogenous base was changed in the DNA that codes for this protein segment. As a result, the glycine in the segment was replaced by valine. This change made the cell cancerous.

i Which nitrogenous base in the DNA was changed? Explain.

ii Given: a nucleotide sequence of DNA

3' CAA CAG CAC CAG CGG 5'

Determine whether the given sequence codes for the flawed section of the protein. Explain your answer.

/Continued on page 22/

12. Glucagon is a hormone excreted by the pancreas whose function is to balance the level of glucose in the blood. A molecule of glucagon in the human body is made up of 29 amino acid units. In a molecule of glucagon, there are 3 units of aspartic acid, Asp, 2 units of arginine, Arg, and 4 units of serine, Ser. The pKa values of the acidic groups in these amino acids are presented in the table below.

Amino acid	Symbol	pKa		
		α-COOH	α-NH_3^+	R (side group)
aspartic acid	Asp	2.1	9.8	3.9
arginine	Arg	2.2	9.0	12.5
serine	Ser	2.2	9.2	

א. i What is the net charge of the particles of aspartic acid in aqueous solution at pH = 6? Explain.

ii Write out a structural formula for particles of arginine in aqueous solution at pH = 10.

iii Using structural formulas, diagram the equilibrium that exists in an aqueous solution of serine at pH = 9.2.

The partial acidic hydrolysis of glucagon yields (among other things) the following two segments I and II:

I Leu – Asp – Ser – Arg

II Ser – Arg – Arg – Aℓa

The pKa of the carboxylic group at the C-terminus of the peptide is close to 3.6.

The pKa of the amino group at the N-terminus of the peptide is close to 8.

ב. i Determine whether the electric charge at each of the end groups will be +1, –1 or zero at pH = 9.

ii Determine the overall charge of Segment I at pH = 9. Explain.

iii Refer to the data in the table and your answer for Sub-item ב i and determine at what pH the isoelectric point of Segment II is found: pH > 12.5, pH = 12.5 or pH < 12.5. Explain.

(Note: This question continues on the next page.)

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ג. Write out a structural formula for Segment I at pH = 2.

ד. Explain why a peptide bond has a rigid, planar structure.

ה. Write out a possible nucleotide sequence for the mRNA (messenger RNA) that was translated into the amino acid sequence shown as Segment I. Label the 3' end and the 5' end.

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Sixth Topic — Environmental Chemistry

13. The main sources of drinking water in Israel are the Kinneret and groundwater. This water needs to be treated appropriately for it to be fit to drink.

א. Water from the Kinneret is filtered through screens and through sand.
Why does the water from the Kinneret need to be filtered through both screens and sand?

For groundwater to be fit to drink, it needs to have been disinfected (microorganisms that are harmful to human health need to be destroyed).

ב. The most widespread method for disinfecting drinking water is chlorination, in which a stream of chlorine gas, $C\ell_{2(g)}$, is sent through the water. Chlorine reacts with water as described by Reactions (1) and (2):

(1) $C\ell_{2(g)} + 2H_2O_{(\ell)} \rightleftharpoons HOC\ell_{(aq)} + H_3O^+_{(aq)} + C\ell^-_{(aq)}$

(2) $HOC\ell_{(aq)} + H_2O_{(\ell)} \rightleftharpoons H_3O^+_{(aq)} + OC\ell^-_{(aq)}$

The disinfection process that involves $HOC\ell_{(aq)}$ is more effective than the disinfection process that involves $OC\ell^-_{(aq)}$ ions.
The efficacy of the disinfection is high in the range $5.5 < pH < 7.5$.

i Explain why the efficacy of the disinfection is low at $pH < 5.5$.

ii Explain why the efficacy of the disinfection is low at $pH > 7.5$.

ג. To soften water, consumers are advised to install an ion-exchange system.

i Explain the concept of soft water.

ii Which type of ion-exchange system is used to soften water — a cation-exchange system or an anion-exchange system?
Explain the principle by which the ion-exchange system that you chose functions.

(Note: This question continues on the next page.)

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ד. Another method for disinfecting drinking water is based on the use of ultraviolet (UV) radiation, which kills a wide range of microorganisms.

i Give one advantage and one disadvantage of this method, as compared to chlorination.

ii A mercury lamp emits UV radiation with a wavelength $\lambda = 255$ nm.
This radiation is suitable for disinfecting drinking water.
Calculate the energy of a photon of radiation of wavelength $\lambda = 255$ nm. Show detailed calculations.

ה. Water that contains lead ions, $Pb^{2+}_{(aq)}$, at a concentration higher than 10 ppb is not fit to drink.
A monitoring station reported on a sample of water in which the concentration of lead ions was $1 \cdot 10^{-7}$ M.
Determine whether the water sample is fit to drink.
Show detailed calculations and explain.

/Continued on page 26/

14. Water is the main component (approx. 90%) of beer. Many breweries were established near springs or wells. The types of ions found in the water and their concentrations affect the quality and flavor of the beer.
To test the hardness of the water, four samples were collected from Well A and titrated with an EDTA solution in the presence of the indicator Eriochrome Black T.

א. i At the end point of the titration, the color of the solution changes. Explain why.

ii In the titration, drops of EDTA solution are added to the sample from a burette. Explain why.

The results of tests to determine the molar concentration of calcium ions, $Ca^{2+}_{(aq)}$, in Well A are presented in the table below.

Sample	Molar concentration of $Ca^{2+}_{(aq)}$ ions (M)
1	0.00027
2	0.00025
3	0.00025
4	0.00023

ב. i Is it possible to determine whether the obtained results are accurate? Explain.

ii Is it possible to determine whether the obtained results are reliable? Explain.

ג. Calculate the hardness of the water in Well A in ppm.
Show detailed calculations.

ד. Soft water is used to make light-colored beers.
Water tests conducted in another well, B, found the hardness of the water in that well to be 130 ppm.
Which of the two wells, A or B, contains water that is better suited for the production of light-colored beer?
Explain.

(Note: This question continues on the next page.)

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Reactions (1)-(4) occur in the presence of $CO_{2(g)}$:

(1) $CO_{2(g)} \rightleftarrows CO_{2(aq)}$

(2) $CO_{2(aq)} + H_2O_{(\ell)} \rightleftarrows H_2CO_{3(aq)}$

(3) $H_2CO_{3(aq)} + H_2O_{(\ell)} \rightleftarrows H_3O^+_{(aq)} + HCO^-_{3(aq)}$

(4) $Ca^{2+}_{(aq)} + 2HCO^-_{3(aq)} \rightarrow CaCO_{3(s)} + CO_{2(g)} + H_2O_{(\ell)}$

An increase in the concentration of $CO_{2(g)}$ in the air can affect the pH and hardness of well water.

ה. i What is one factor that could cause an increase in the concentration of $CO_{2(g)}$ in the air?

ii Determine whether the pH of the well water will increase, decrease or stay the same following an increase in the concentration of $CO_{2(g)}$ in the air. Explain.

iii An increase in the concentration of $CO_{2(g)}$ in the air can decrease the hardness of the water.
Explain why.

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Seventh Topic – Expertise in the Research Laboratory

Note: Students who took Research Laboratory for one point must answer Question 15.

15. Read the passage below and answer all of the items that follow.

Fluoride Ions, F^-, Teeth and Eggshells — What's the Connection?

Tooth decay is an infectious disease of teeth that is caused by bacteria. The bacteria cling to the tooth surface and cause the breakdown of the carbohydrates in food and the production of acids.

Tooth enamel is made of hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_{2(s)}$, which is the hardest material in the human body. Hydroxyapatite reacts with acids as described in Reaction (1):

(1) $Ca_{10}(PO_4)_6(OH)_{2(s)} + 8H_3O^+_{(aq)} \longrightarrow 10Ca^{2+}_{(aq)} + 6HPO^{2-}_{4(aq)} + 10H_2O_{(\ell)}$

Continued exposure to acids causes the development of tooth decay.

Researchers have proven that low concentrations of fluoride ions, F^-, help to prevent tooth decay.

F^- ions replace some of the hydroxide ions, OH^-, of hydroxyapatite via Reaction (2):

(2) $Ca_{10}(PO_4)_6(OH)_{2(s)} + 2F^-_{(aq)} \longrightarrow Ca_{10}(PO_4)_6F_{2(s)} + 2OH^-_{(aq)}$

Fluoride apatite, $Ca_{10}(PO_4)_6F_{2(s)}$, is formed. Fluoride apatite is more resistant to acids than hydroxyapatite.

The main component of eggshells is calcium carbonate, $CaCO_{3(s)}$, which reacts with acids as described in Reaction (3):

(3) $CaCO_{3(s)} + 2H_3O^+_{(aq)} \longrightarrow Ca^{2+}_{(aq)} + CO_{2(g)} + 3H_2O_{(\ell)}$

In the presence of F^- ions, calcium fluoride, $CaF_{2(s)}$ is produced as described in Reaction (4):

(4) $CaCO_{3(s)} + 2F^-_{(aq)} \longrightarrow CaF_{2(s)} + CO^{2-}_{3(aq)}$

Calcium fluoride is a salt that does not dissolve easily. It increases the resistance of eggshells to acids. Teeth and eggshells react similarly with acids and with F^- ions. Therefore, for research purposes, eggshells are used in experiments as a substitute for teeth.

(Note: This question continues on the next page.) /Continued on page 29/

An experiment was carried out to prove that exposure to F^- ions increases the resistance of eggshells to acetic acid, $CH_3COOH_{(aq)}$. The experimental process is described below:

We prepared six samples of eggshells (1 gram per sample). We took five of these samples and soaked them each in 2 mL of sodium fluoride solutions ($NaF_{(aq)}$) of different concentrations for 30 minutes. Then, we rinsed the eggshells in distilled water and put each sample into 5 mL of a 1 M $CH_3COOH_{(aq)}$ solution. We measured the time it took for 3 mL of $CO_{2(g)}$ to be emitted.

The results of the experiment are presented in the table below.

Concentration of the $NaF_{(aq)}$ solution (M)	0 (control)	0.25	0.50	0.75	1.00
Time (seconds)	30	40	52	67	85

The sixth sample was used as an additional control. It underwent the same treatment as the other five samples, with one difference: The eggshells were left in 2 mL of a 1 M sodium chloride solution, $NaCl_{(aq)}$, for 30 minutes. The time needed for the emission of 3 mL of $CO_{2(g)}$ was 32 seconds.

Adapted from: http://www.bfsweb.org/documents/howfworks.htm
W. Lukowsky, "Does F^- protect?", CHEM 13 NEWS, Oct. 1994

Answer <u>all</u> of the items below.

א. i Formulate research questions for the experiment described above.

ii Two controls were used in the experiment.
What was the purpose of each of the controls?

ב. i Present the results of the experiment that are shown in the table in graphical form.

ii Explain the results of the experiment, based on the information in the passage.

iii What are <u>two</u> conclusions that can be drawn from the results of the experiment?

(Note: This question continues on the next page.) /Continued on page 30/

ג. In another experiment, researchers evaluated the effect of the amount of time that the eggshells were left in $NaF_{(aq)}$ solution on their resistance to acetic acid. The researchers measured the volume of $CO_{2(g)}$ that was emitted over a minute.

i Identify the dependent variable and the independent variable in this experiment.

ii Identify four fixed factors in this experiment.

ד. Fluoridation of drinking water is a controlled process in which fluoride compounds are added to drinking water in order to reduce the incidence of tooth decay in the population. The concentration of F^- ions should be no greater than 0.0017 grams per liter. Higher concentrations of F^- ions in drinking water can have negative effects.

i Calculate the maximum permissible molar concentration of fluoride ions in drinking water. Show detailed calculations.

ii In the experiment described in the passage, eggshells were not soaked in fluoridated drinking water. Explain why.

Good Luck!

בהצלחה!