**State of Israel**
**Ministry of Education**
Exam Type:
*Bagrut* for high schools
Exam date: Summer 2016
**Exam number: 037203**
Attachment: Formulas and data for Chemistry
**English Translation (3)**

**מדינת ישראל**
**משרד החינוך**
סוג הבחינה:
בגרות לבתי ספר על־יסודיים
מועד הבחינה: קיץ תשע"ו, 2016
**מספר השאלון: 037203**
נספח: נוסחאות ונתונים בכימיה
**תרגום לאנגלית (3)**

# Chemistry

*Hashlama* from 3 to 5 points
For students studying taking a
full unit of Research Laboratory

# כ י מ י ה

השלמה מ–3 ל–5 יחידות לימוד
לתלמידים הלומדים יחידה שלמה של מעבדת חקר

## Instructions for examinees

א. Duration of the exam: One and a half hours

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

| | | | |
|---|---|---|---|
| Part One | — | (1×50) — | 50 points |
| Part Two | — | (1×50) — | 50 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 instruction:
**On the outside cover of your exam booklet, list the topic in Part Two on which you chose to answer questions.**

Write only in the exam booklet. Write whatever you wish to write as a draft (notes, calculations, 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 exam booklet, your exam may be disqualified!

**Good Luck!**

## הוראות לנבחן

א. משך הבחינה: שעה וחצי.

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

| | | |
|---|---|---|
| פרק ראשון | — | (50x1) — 50 נקודות |
| פרק שני | — | (50x1) — 50 נקודות |
| | | סה"כ — 100 נקודות |

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

ד. הוראה מיוחדת:
**רשום על הצד החיצוני של מחברת הבחינה את הנושא שענית עליו 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!**

# Questions

## Part One (50 points)

## Required Topic — Energy and Kinetics (1)

Answer one of the questions 1-2.

**Note: Make sure that all equations are balanced and that units are written correctly.**

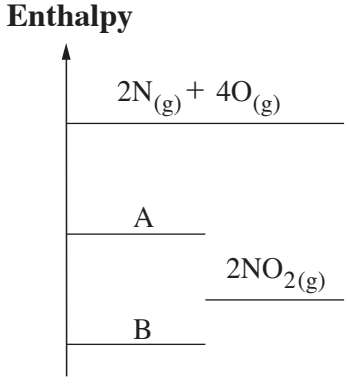
**1.** This question concerns reactions involving nitrogen oxides.

Two reactions are given, (1)-(2):

(1) $N_{2(g)} + 2O_{2(g)} \longrightarrow 2NO_{2(g)}$ $\qquad \Delta H_1^o = +66.4$ kJ

(2) $2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$ $\qquad \Delta H_2^o = -114.4$ kJ

The diagram below shows the change in standard enthalpy in Reactions (1)-(2) as bonds in the reactant molecules are broken and bonds are formed in the molecules of the products.




**א.** i Is the breaking of bonds in the reactant molecules an exothermic process or an endothermic process? Explain.

ii Write out an equation to describe the breaking of the bonds in the reactant molecules for each reaction, (1) and (2).

iii Copy the diagram into your answer booklet and, on each of the lines A and B, fill in the formula of the appropriate reactant. Explain.

/Continued on page 3/

**ב.** Reaction (3) is given:

$$(3)\quad 2NO_{(g)} \longrightarrow N_{2(g)} + O_{2(g)} \qquad \Delta H_3^o$$

Calculate the value of $\Delta H_3^o$. Show detailed calculations.

**ג.** i Does Reaction (1) proceed spontaneously under standard conditions at a temperature of 298 K?
Explain without doing any calculations.

ii The change in standard entropy in Reaction (3) is $\Delta S^o_{\text{system}} = -24.6\frac{J}{K}$.
Does Reaction (3) proceed spontaneously under standard conditions at a temperature of 298 K?
Show detailed calculations and explain.

**ד.** Gases emitted from a car engine pass through a device known as a catalytic converter.
The job of this device is to limit the emission of polluting gases into the air. These gases include the oxide $NO_{(g)}$, which is produced in the engine. As the gases pass through the catalytic converter,
Reaction (3) occurs on a platinum, $Pt_{(s)}$, surface that serves as a catalyst.
The products of Reaction (3) are emitted into the air along with the rest of the gases.

i Two statements, **a** and **b**, are presented below. Determine which statement, **a** or **b**, is correct.
Explain why you rejected the other statement.

**a** The change in enthalpy in Reaction (3), when it occurs on a $Pt_{(s)}$ surface, is smaller than the change in enthalpy in Reaction (3) when the reaction proceeds without any $Pt_{(s)}$.

**b** The activation energy [אנרגיית השפעול] for Reaction (3) on a $Pt_{(s)}$ surface is lower than the activation energy for Reaction (3) when no $Pt_{(s)}$ is present.

ii Can Reaction (3) reach a state of equilibrium in the catalytic converter while the engine is running? Explain.

/Continued on page 4/

**2.** Carbon monoxide, $CO_{(g)}$, is a poisonous gas that is odorless and colorless. $CO_{(g)}$ is produced through the combustion of cooking gas (among other things). In order to prevent carbon monoxide, $CO_{(g)}$, poisoning, carbon monoxide detectors that sound an alarm when this gas is present are installed in laboratories and homes.

Reaction (1) occurs in a carbon monoxide detector:

(1) $CO_{(g)} + \frac{1}{2}O_{2(g)} \longrightarrow CO_{2(g)}$

Standard molar entropy values, $S^o$, of the reactants and product of Reaction (1) are shown in the table below:

| $O_{2(g)}$ | $CO_{(g)}$ | $CO_{2(g)}$ | **Substance** |
|---|---|---|---|
| 205.0 | 197.9 | 213.6 | **Standard molar entropy, $S^o$** $\left(\frac{J}{K \cdot mol}\right)$ |

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

ii Reaction (1) proceeds spontaneously under standard conditions at a temperature of 298 K. Is Reaction (1) endothermic or exothermic? Explain.

In industrial settings, $CO_{(g)}$ is produced for different purposes through Reaction (2):

(2) $C_{(s)} + CO_{2(g)} \longrightarrow 2CO_{(g)} \qquad \Delta H^o_2 = +173\ kJ \qquad \Delta S^o_2 = +176.3\ \frac{J}{K}$

**ב.** i Explain why $\Delta S^o_2 > 0$.

ii Does Reaction (2) proceed spontaneously under standard conditions at a temperature of 298 K?
Show detailed calculations and explain.

/Continued on page 5/

The gas $CO_{(g)}$ is used to produce formaldehyde [מתאנאל], $CH_2O_{(g)}$, which is a raw material used in the manufacturing of plastic products.

Formaldehyde is produced through Reaction (3):

(3) $CO_{(g)} + H_{2(g)} \rightleftarrows CH_2O_{(g)} \qquad \Delta H_3^o < 0$

**ג.** i Write the expression of the equilibrium constant, $K_c$, for Reaction (3).

ii The value of the equilibrium constant for Reaction (3) at 298 K is $K_c = 4.1 \cdot 10^{-4}$.

The following were put into a closed container that had a volume of 1 liter: 0.01 mols of $CO_{(g)}$, 0.01 mols of $H_{2(g)}$ and 0.008 mols of $CH_2O_{(g)}$.

Is the rate of the forward reaction, until the point at which equilibrium is reached, faster or slower than the rate of the reverse reaction? Explain.

**ד.** Two statements, i-ii, concerning Reaction (3) in a closed container are presented below.

Determine whether each statement is true or false. Explain each of your answers.

i In a state of equilibrium, the total number of molecules in the system is constant.

ii The value of $K_c$ at 1000 K will be greater than $4.1 \cdot 10^{-4}$.

/Continued on page 6/

# Part Two (50 points)

Part Two includes seven topics (questions 3-16). You must answer one question.
**On the outside cover of the answer booklet, write the topic for which you answered questions in Part Two.**

## First Topic — Bromine and Its Compounds

**Note: Make sure that all equations are balanced and that units are written correctly.**

**3.** This question concerns the production of calcium bromide solution, $CaBr_{2(aq)}$, at the Bromine Compounds factory in Ramat Hovav.
There are two methods for producing $CaBr_{2(aq)}$ solution, which each use a solution of hydrobromic acid, $HBr_{(aq)}$, as one of the necessary raw materials.

In the first method, $HBr_{(aq)}$ solution reacts with chalk, $CaCO_{3(s)}$, as shown in Reaction (1):

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

In the second method, $HBr_{(aq)}$ solution reacts with calcium hydroxide, $Ca(OH)_{2(s)}$, as shown in Reaction (2):

(2) $Ca(OH)_{2(s)} + 2H_3O^+_{(aq)} + 2Br^-_{(aq)} \longrightarrow Ca^{2+}_{(aq)} + 2Br^-_{(aq)} + 4H_2O_{(\ell)}$

**א.** i It is cheaper to use the first method to produce $CaBr_{2(aq)}$.
Explain why.

ii Why is $HBr_{(aq)}$ solution used in the two production methods, as opposed to hydrogen bromide gas, $HBr_{(g)}$?
Give one reason.

**ב.** The main disadvantage of the first method is that the gas $CO_{2(g)}$ is produced.

i What is one reason why the production of $CO_{2(g)}$ is a disadvantage?

ii What is done in the factory to compensate for this disadvantage?

/Continued on page 7/

**ג.** In the production process carried out using the first method, the percent conversion [אחוז ההמרה] is 100% and the percentage yield [אחוז הניצולת] is 95%.

i Explain why the percent conversion for this process is 100%.

ii 20,000 liters of $HBr_{(aq)}$ solution with a concentration of 5.47 M were added to the reaction tank, which contained an appropriate amount of $CaCO_{3(s)}$. The reactants reacted completely.
Calculate the concentration of the $CaBr_{2(aq)}$ solution that was obtained. Show detailed calculations.
Assume that the volume of the solution did not change over the course of the reaction.

**ד.** The production of $CaBr_{2(aq)}$ using the second method involves three main steps, I-III:

I Production of $CaBr_{2(aq)}$ solution via Reaction (2)

II Filtering the solution obtained in Step I

III Evaporating some of the water from the solution, in order to obtain a more concentrated solution that meets the demands of the market.

Draw a diagram of this process that includes the three steps.
In your diagram, write the formulas of the substances entering and leaving each tank.
Draw arrows to indicate the direction in which each substance flows.

**ה.** Another method for obtaining concentrated $CaBr_{2(aq)}$ solution is to add solid $CaBr_{2(s)}$ to a dilute solution.
What is one advantage of this method, as compared to evaporating water from a dilute solution?

/Continued on page 8/

**4.** This question concerns uses of bromine compounds.

**א.** Today, bromine, $Br_{2(\ell)}$, is often transported, but, during the Second World War, calcium bromide, $CaBr_{2(s)}$, was shipped by boat to the country where the bromine was to be used and only then was $Br_{2(\ell)}$ produced from it.

i Give <u>one</u> advantage and <u>one</u> disadvantage of transporting $CaBr_{2(s)}$ to be used as a source for $Br_{2(\ell)}$.

ii Describe the manner and the containers in which bromine is transported today.

**ב.** Solutions that contain $CaBr_2$, as well as other salts such as $ZnBr_2$ and NaBr, are used in oil wells.

Is the statement below true or false? <u>Explain</u>.

"The composition of the solutions is set based on the temperature conditions in the area of the well, among other things."

**ג.** Aqueous solutions of sodium hypochlorite, $NaC\ell O_{(aq)}$, are used to disinfect the water in swimming pools.

When $NaBr_{(s)}$ is added to a $NaC\ell O_{(aq)}$ solution, Reactions (1) and (2) occur:

(1) $Br^-_{(aq)} + C\ell O^-_{(aq)} \rightleftharpoons BrO^-_{(aq)} + C\ell^-_{(aq)}$

(2) $BrO^-_{(aq)} + H_2O_{(\ell)} \rightleftharpoons HOBr_{(aq)} + OH^-_{(aq)}$

Adding $NaBr_{(s)}$ to a $NaC\ell O_{(aq)}$ solution increases the disinfecting power of the solution.

<u>Explain this fact</u>.

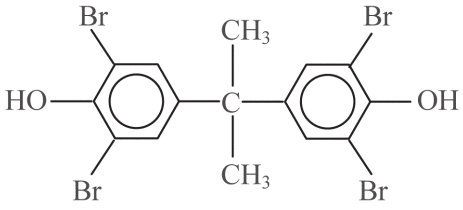
**ד.** Ammonium bromide, $NH_4Br_{(s)}$, is used as a supplemental flame retardant [מעכב בערה מוסף], mainly for items made of wood or paper.

i Explain why $NH_4Br_{(s)}$ can be used as a flame retardant.

ii Explain why $NaBr_{(s)}$ <u>cannot</u> be used as a flame retardant.

/Continued on page 9/

**ה.** The substance TBBA (tetrabromobisphenol A),




,

can be used as a flame retardant for plastic objects made of polymers.

i Three statements, **a-c**, are shown below.

Determine which of the statements (one or more) relate(s) to the ability of TBBA to function as a supplemental flame retardant.

**a** In a TBBA molecule, there are four bromine atoms.

**b** In a TBBA molecule, there are two $-OH$ groups.

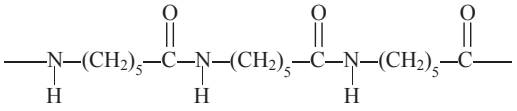
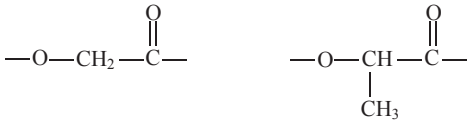
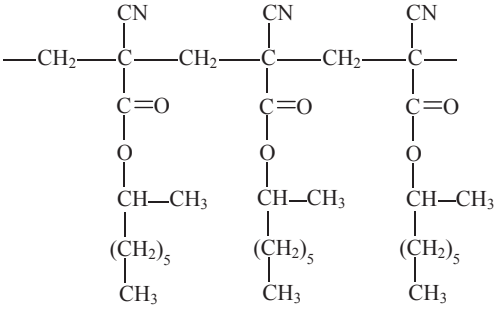
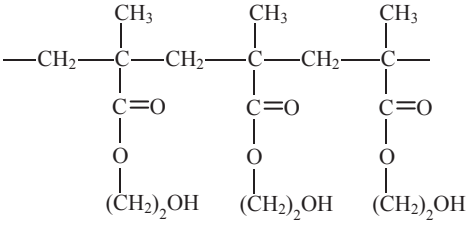
**c** In a plastic object, forces of attraction are produced between the molecules of TBBA and the molecules of the polymer.

ii TBBA can also be used as an active flame retardant [מעכב בערה פעיל]. Explain why.

/Continued on page 10/

## Second Topic — Polymers

**5.** Representative segments of several polymers used in surgery are presented in the table below.

| Surgical uses | Representative segment | Polymer name | |
|---|---|---|---|
| Thread for external stitches, which need to be removed from the body after about two weeks |  | nylon 6 | (1) |
| Thread for internal stitches, which break down in the body after several weeks | — ABAAABBAAABBBABAA —<br>  <br>B A | random copolymer of polylactic acid and polyglycolic acid | (2) |
| Medical glue used in surgery instead of external stitches |  | 2-octyl-2-cyanoacrylate | (3) |
| Bone repair – material used to fill in missing pieces of bone |  | polyhydroxy-ethyl-methacrylate | (4) |

**א.** i Determine which method – condensation [דחיסה] or addition [סיפוח] – is used to prepare <u>each</u> of the polymers (1)-(4).

ii Write out the structural formulas of the monomers for the <u>two</u> polymers (1) and (4) only.

/Continued on page 11/

**ב.** The random copolymer (2) is made up of A units and B units.
In a laboratory, two samples of Copolymer (2) were prepared under the same conditions.
The two samples had the same degree of polymerization.
In Sample I, there were more A units than B units.
In Sample II, there were more B units than A units.

i The intermolecular forces in the copolymer in Sample II were stronger than the intermolecular forces in the copolymer in Sample I. Explain this fact.

ii Determine whether the degree of crystallinity [אחוז הגבישיות] of the copolymer in Sample II was higher, lower or the same as the degree of crystallinity of the copolymer in Sample I.

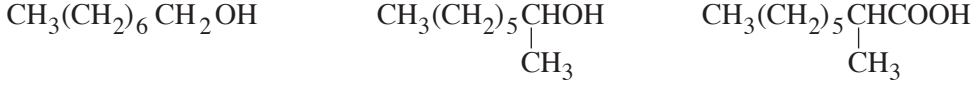
**ג.** i During an operation, incisions made inside the body are sewn up using thread made of Copolymer (2).
This thread breaks down in the body over a period of several weeks as it is hydrolyzed by bodily fluids (which are mostly water).
Write out the structural formulas of the products of the complete hydrolysis of Copolymer (2).

ii Polymer (4) can also be hydrolyzed by bodily fluids, but that hydrolysis does not affect its degree of polymerization.
Explain this fact.

**ד.** Polymer (3) is obtained from the monomer at the moment the surgical wound is glued.

i Write out the structural formula of the monomer.

ii Under suitable conditions, Polymer (3) is broken down by hydrolysis.
Formulas of three substances, I-III, are shown below:

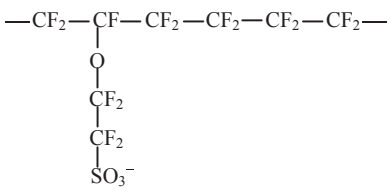
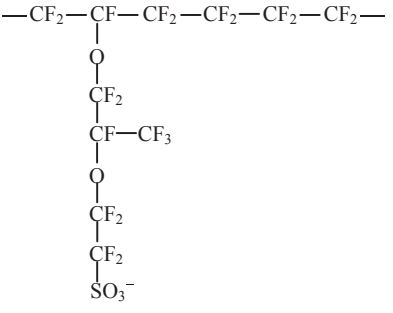
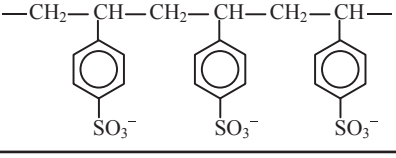


**I** **II** **III**

Determine which of the substances I-III is one of the products of the hydrolysis of Polymer (3).

/Continued on page 12/

**6.** This question concerns polymers that contain a sulfonic, $SO_3^-$, side group. Segments of three polymers, (1)-(3), and their glass transition temperatures, Tg, are presented in the table below.

| **Glass transition temperature** Tg (°C) | **Structural formula of a segment of the polymer** | **Polymer** |
|---|---|---|
| 100 |  | (1) |
| 140 |  | (2) |
| 152 |  | (3) |

**א.** i Determine whether Polymers (1) and (3) are <u>each</u> a product of the polymerization of one monomer or the polymerization of two monomers.

ii Write out the structural formulas of the monomers used to produce Polymers (1) and (3).

**ב.** i Explain why the Tg value of Polymer (2) is higher than the Tg value of Polymer (1).

ii Explain why the Tg value of Polymer (3) is higher than the Tg value of Polymer (2).

**ג.** The gases used to anesthetize patients during surgery can contain water. Polymer (2) is used to absorb the water from those gases. Explain why Polymer (2) absorbs water.

/Continued on page 13/

**ד.** In a laboratory, two samples, I and II, of Polymer (3) were prepared from identical amounts of monomer.

In the preparation of Sample I, 1 gram of initiator [יזם] was used and, in the preparation of Sample II, 5 grams of initiator were used.

Determine whether each of the statements below, i-ii, is true or false.

Explain each of your answers.

i The repeating unit of the polymer in Sample I is shorter than the repeating unit of the polymer in Sample II.

ii The average degree of polymerization of the polymer in Sample I is higher than the average degree of polymerization of the polymer in Sample II.

**ה.** Polymer (3) cannot be used to produce fibers. Explain why.

/Continued on page 14/

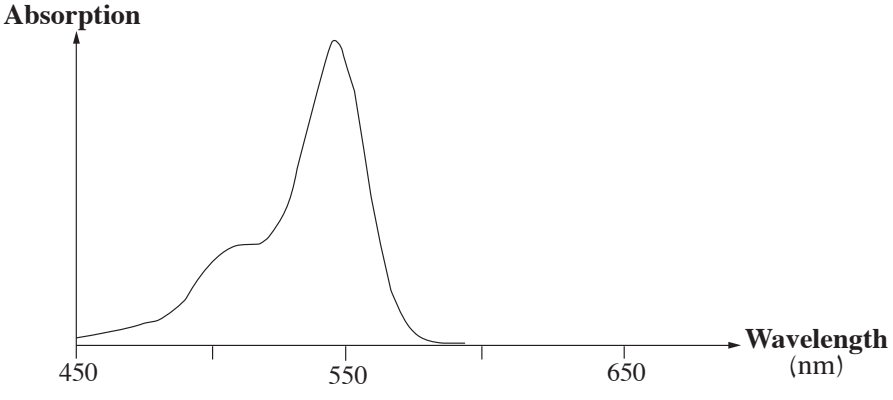
# Third Topic — Physical Chemistry — From the Nano Level to Microelectronics

**Note: Make sure that all equations are balanced and that units are written correctly.**

**7.** Photodynamic therapy involving light within the visible range can destroy certain cancerous tumors, without any surgery or side effects.

**א.** i In the first phase of the treatment, a colored organic compound (pigment) is injected into the area of the tumor. The pigment molecules are absorbed mainly by the cancerous cells.
What are two structural characteristics of the pigment molecules?

ii The absorption spectrum of a pigment used for this type of treatment is presented below.
According to the absorption spectrum, what color is this pigment? Explain.




**ב.** In the second phase of the treatment, radiation of the appropriate wavelength is directed at the cancerous cells that absorbed the pigment molecules. The pigment molecules absorb this radiation and their electrons are excited. In order to excite the electrons of the pigment molecules, what wavelength of radiation should be directed at them: 543 nm or 650 nm? Explain.

/Continued on page 15/

**ג.** The radiation emitted by the excited pigment molecules is absorbed by oxygen, $O_2$, molecules in the tissue. Those oxygen molecules are excited. The excited oxygen molecules act as a strong oxidant, destroying the tissue of the cancerous tumor around them.

i Write out the configuration of electrons in a molecule of oxygen in its ground state [מצב אלקטרוני יסודי].

ii Label the HOMO orbital and the LUMO orbital in the configuration of electrons of a molecule of oxygen in its ground state.

**ד.** i The energy needed to excite one molecule of oxygen is $1.566 \cdot 10^{-19}$ J.

Calculate the wavelength of the radiation that could be used to excite an oxygen molecule.

Show detailed calculations.

ii Is radiation of the wavelength that you calculated for Sub-item ד i within the ultraviolet range, the range of visible light or the infra-red range?

**ה.** Determine whether each of the statements below, **a-c**, is true or false.

**a** The bond order of an oxygen molecule in its ground electronic state is 1.

**b** Oxygen molecules absorb radiation within the visible range.

**c** When visible light is absorbed, electrons in the pigment molecules are transferred from the HOMO orbital to a higher-energy orbital.

/Continued on page 16/

**8.** This question concerns the radiation emitted by different bulbs.

**א.** In the past, mercury bulbs were used in streetlights.
The two main lines in the emission spectrum of mercury bulbs, within the visible range, are at the following wavelengths: 466 nm and 546 nm.

i Determine the color of the visible light at <u>each</u> of these wavelengths in the emission spectrum.

ii Calculate the photon energy that corresponds to <u>each</u> of the given wavelengths.
<u>Show detailed calculations</u>.

**ב.** Some advertisement signs are made up of bulbs that contain excited neon atoms.
Two of the main frequencies of the radiation emitted by a lit-up neon sign are:
$4.27 \cdot 10^{14}$ Hz and $4.83 \cdot 10^{14}$ Hz.

i What color will a lit-up neon sign appear to the human eye: red or blue? <u>Show detailed calculations and explain</u>.

ii Write out the electron configuration of a neon atom in its ground state.

iii Write out <u>one</u> possible configuration of the electrons of a neon atom in an excited state.

**ג.** Certain energy-saving bulbs, which emit white light, are produced by joining together three different types of light-emitting diodes (LED).
Data regarding the wavelengths of radiation emitted by five light-emitting diodes are presented below.

| Light-Emitting Diode | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Wavelength (nm) | 390 | 480 | 500 | 650 | 810 |

i From the table, choose <u>three</u> light-emitting diodes that could be joined together to produce a bulb that emits white light.
<u>Explain your choice</u>.

ii Two statements, **a** and **b**, are shown below. Which statement, **a** or **b**, is correct?
<u>Explain why you rejected the other statement</u>.

**a** When light-emitting diodes are turned on, electrons are transferred from the conduction band [פס ההולכה] to the valence band [פס הערכיות].

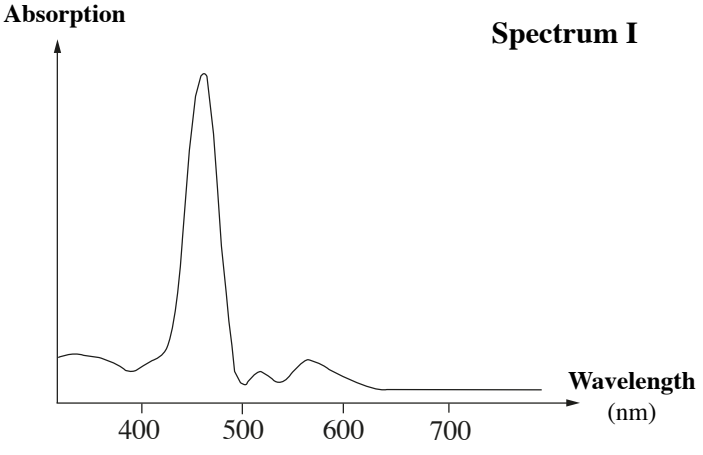
**b** The energy gap between the conduction band and the valence band is largest in Diode (5).

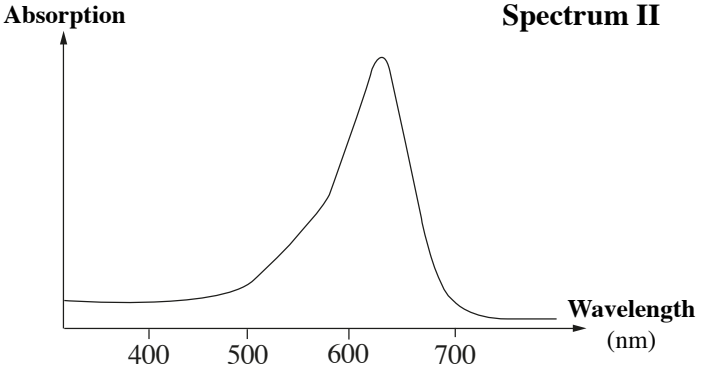
/Continued on page 17/

**7.** Under appropriate conditions, food can be preserved without preservatives, by irradiating it with the light emitted by a blue LED. This light is absorbed by porphyrins, which are compounds found in bacterial cells.

This absorption of light triggers a chain reaction, which destroys the cells of the bacteria in the food.

Two spectra are shown below:




i Which of these two spectra is the absorption spectrum of porphyrin? Explain.

ii Can a red LED be used to preserve food? Explain.

/Continued on page 18/

## Fourth Topic — Advanced Organic Chemistry

**9.** This question concerns reactions of 2-chloropropane, $CH_3-\underset{\underset{C\ell}{|}}{CH}-CH_3$, with different nucleophiles.

Solutions of 2-chloropropane in an appropriate solvent were put into four containers, (1)-(4).

A nucleophile solution was added to <u>each</u> of these containers and a reaction occurred in each container.

Information about the solvents, the nucleophile added to each container and the reaction products is presented in the table below.

| Reaction Product(s)* | Nucleophile | Solvent | Container |
|---|---|---|---|
| A and B | $CH_3O^-$ | methanol, $CH_3OH_{(\ell)}$ | (1) |
| A only | $OH^-$ | methanol, $CH_3OH_{(\ell)}$ | (2) |
| ? | $(CH_3)_3CO^-$ | t-butanol, $(CH_3)_3COH_{(\ell)}$ | (3) |
| C only | $Br^-$ | methanol, $CH_3OH_{(\ell)}$ | (4) |

* The letters A, B and C represent different compounds.

**א.** i The boiling point of product A is lower than the boiling point of Product B.

Write the structural formulas of the two products, A and B, of the reaction that occurred in Container (1).

ii By which mechanism was <u>each</u> of the two products in Container (1) obtained?

**ב.** i In the solvent methanol, $OH^-_{(CH_3OH)}$ ions are a stronger base than $CH_3O^-_{(CH_3OH)}$ ions.

Explain how that conclusion can be reached based on the information given about the reactions that occurred in Containers (1) and (2).

ii Write out the mechanism of the reaction that occurred in Container (2).

/Continued on page 19/

**ג.** Two statements, i and ii, are shown below. Determine whether each statement is true or false. Explain each of your answers.

i An increase in the temperature in Container (1) will increase the percentage of Product A in the reaction mixture.

ii An increase in the concentration of $OH^-_{(CH_3OH)}$ ions in Container (2) will increase the reaction rate.

**ד.** Write out the structural formula(s) for the product or products of the reaction that occurred in Container (3).

**ה.** i Write out the equation of the reaction that occurred in Container (4).

ii Explain why no Product A was obtained in Container (4).

/Continued on page 20/

**10.** This question concerns the effect of the solvent on substitution reactions of alkyl halides.

**א.** A list of four solvents is shown below:

acetone, $CH_3COCH_{3(\ell)}$, water, $H_2O_{(\ell)}$, methanol, $CH_3OH_{(\ell)}$

and dimethylformamide (DMF), $H-\overset{\overset{O}{\|}}{C}-N(CH_3)_{2(\ell)}$.

Determine which of these solvents are protic solvents and which are aprotic polar solvents.

The table below shows information regarding reaction times of methyl iodide, $CH_3I$, and bromide ions, $Br^-$, in two solvents, methanol and DMF, at 25°C. The concentration of each reactant was the same in the two solvents.

| DMF | Methanol | Solvent |
|---|---|---|
| 8.7 seconds | 12 hours | Reaction time: amount of time needed for the reaction to proceed to completion |

**ב.** i Write out the equation for the reaction between methyl iodide and $Br^-_{(CH_3OH)}$ ions in methanol.

ii By which mechanism does this reaction proceed?

iii Explain why the reaction time in methanol solution was longer than the reaction time in DMF solution.

**ג.** i The reaction between methyl iodide and chloride ions, $C\ell^-_{(CH_3OH)}$, was carried out in a methanol solution.
Was the reaction time for this reaction between methyl iodide and chloride ions, $C\ell^-_{(CH_3OH)}$, longer than, shorter than or exactly 12 hours? Explain.

ii The reaction time for the reaction between methyl iodide and $C\ell^-_{(DMF)}$ ions was 1.4 seconds.
Which nucleophile is stronger in DMF solution: $C\ell^-_{(DMF)}$ or $Br^-_{(DMF)}$?

/Continued on page 21/

**7.** 2-bromo-2-methylbutane, $CH_3-CH_2-\underset{\displaystyle Br}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH_3$, reacts with $H_2O_{(\ell)}$ as shown below:

$$CH_3-CH_2-\underset{\displaystyle Br}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH_3 + 2H_2O_{(\ell)} \longrightarrow CH_3-CH_2-\underset{\displaystyle OH}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH_3 + H_3O^+_{(aq)} + Br^-_{(aq)}$$

i Write out the equation for the first step in the mechanism of this reaction.

ii The reaction was carried out in two different mixtures of the solvents water and acetone.

In the solvent mixture that contained 70% water and 30% acetone, the reaction proceeded more quickly than it did in the solvent mixture that contained 30% water and 70% acetone. Explain why.

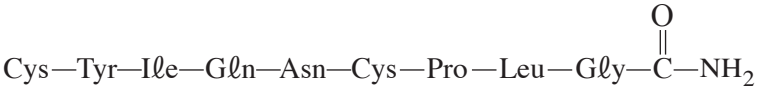
/Continued on page 22/

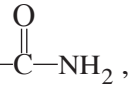
## Fifth Topic — Chemistry of Proteins and Nucleic Acids

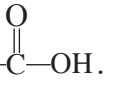
**11.** The peptide oxytocin is a hormone secreted by the pituitary gland that plays a role in many systems of the body. For example, it intensifies the contractions of the uterus during childbirth.

In a molecule of oxytocin, there are nine amino acid residues.

The amino acid sequence of a molecule of oxytocin is shown below:



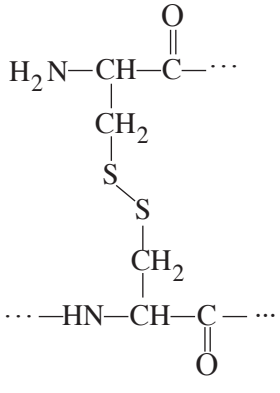

On the glycine residue, Gly, at the C-terminus of the molecule, there is an amide group, 

, instead of a carboxyl group, 

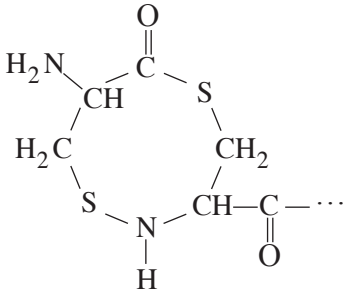
.

**א.** A molecule of oxytocin has a ring structure that is created by a disulfide bond between the two cysteine, Cys, residues present in the molecule. Two structural formulas are shown below, **a** and **b**. Determine which of these structural formulas, **a** or **b**, is the correct structural formula for a representative segment of the disulfide bond between the two cysteine, Cys, residues in an oxytocin molecule. Explain.

**b**




**a**




/Continued on page 23/

**ב.** In a laboratory experiment carried out under the appropriate conditions, oxytocin was partially broken down. One of the products of this decomposition was Tetrapeptide [ארבע-פפטיד] **I**:

**I** Asn–Cys–Pro–Leu

i How does the structure of a molecule of proline, Pro, differ from the structures of the molecules of the other amino acids used to form Tetrapeptide **I**?

ii pKa values of the acidic groups of Tetrapeptide **I** are shown below:
The pKa of the C-terminus is 3.6.
The pKa of the N-terminus is 8.
What is the overall charge of Tetrapeptide **I** at a pH of 7?

**ג.** The peptide vasopressin is another hormone secreted by the pituitary gland. Vasopressin is responsible for regulating urination, among other things.

Vasopressin molecules are similar to oxytocin molecules, in terms of their composition and structure.

Each of these molecules is made up of nine amino acid residues.

However, in a molecule of vasopressin, instead of Ile and Leu, there are residues of two other amino acids.

In a laboratory experiment carried out under the appropriate conditions, vasopressin was partially broken down. One of the products of this decomposition was Tetrapeptide **II**:

**II** Asn–Cys–Pro–X

X represents an amino acid residue.

The overall charge of Tetrapeptide **II** at a pH of 7 is +1.

i Four amino acids are given: Asp, Arg, Glu and Val.
The X residue in Tetrapeptide **II** is a residue of one of the given amino acids. Which one is it? Explain.

ii Write out the full structural formula of Tetrapeptide **II** at pH = 7.

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

/Continued on page 24/

**ד.** A nucleotide sequence of DNA is shown below. Following transcription and translation, one of the tetrapeptides, **I** or **II**, will be obtained from this DNA sequence.

3' TTA ACA GGT TCC 5'

i Write out the nucleotide sequence of the mRNA that is produced through the transcription of the given DNA sequence. Label the 3' end and the 5' end.

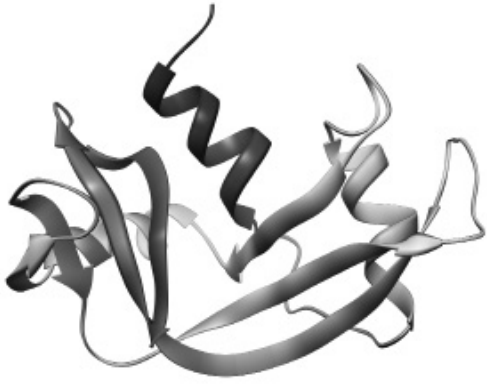
ii Will the translation of the mRNA sequence that you wrote out for Sub-item ד i yield Tetrapeptide **I** or Tetrapeptide **II**? Explain.

**ה.** Write out one possible nucleotide sequence for the mRNA whose translation would yield the other tetrapeptide (the one you did not choose as your answer for Sub-item ד ii). Label the 3' end and the 5' end.

/Continued on page 25/

**12.** The enzyme ribonuclease is a spherical protein whose structure was first determined by the biochemist Anfinsen. For his discovery, he was awarded the Nobel Prize in Chemistry in 1972.

A model of the spatial structure of a molecule of ribonuclease is presented below:



**א.** i The forces that act between the side groups of the amino acid residues stabilize the tertiary [שלישוני] structure of the protein. What are <u>three</u> types of forces that stabilize the tertiary structure?

ii Ribonuclease is a water-soluble protein. Explain how the spatial structure of the molecules allows ribonuclease to dissolve in water.

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

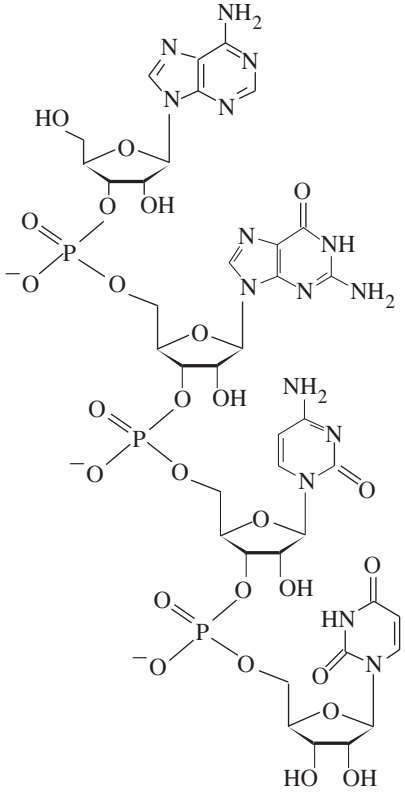
/Continued on page 26/

**ב.** A strand of RNA is partially hydrolyzed in the presence of the enzyme ribonuclease. The strand of RNA is broken down into molecules that include short sequences of nucleotides.

The spatial structure of a molecule obtained from the partial hydrolysis of a strand of RNA is presented below.

We will refer to this molecule as A.

**A**



i Based on its spatial structure, explain how we know that Molecule A was obtained from the partial hydrolysis of a strand of RNA and not from the partial hydrolysis of a strand of DNA. Give <u>two</u> explanations.

ii Write out the nucleotide sequence of Molecule A. Label the 3' end and the 5' end.

/Continued on page 27/

**ג.** Two codons can be found in the sequence that you wrote out for Sub-item ב ii.

i Write out the nucleotide sequences of both codons. Label the 3' end and the 5' end.

ii What two amino acids could be obtained from the translation of the given nucleotide sequence?

**ד.** Write out the nucleotide sequence of the section of the strand of DNA whose transcription yields the sequence that you wrote out for Sub-item ב ii. Label the 3' end and the 5' end.

**ה.** When heated to 100°C, the double helix of DNA breaks down into two separate strands.

i Which bonds in the double helix of DNA break down at 100°C?

ii When heated to 100°C, a single strand of DNA will not break apart into nucleotides. Explain why.

/Continued on page 28/

# Sixth Topic — Environmental Chemistry

**Note: Make sure that all equations are balanced and that units are written correctly.**

**13.** A creek in northern Israel was contaminated with wastewater containing nickel ions, $Ni^{2+}_{(aq)}$.

Water in which the concentration of $Ni^{2+}_{(aq)}$ is higher than 0.02 ppm is considered hazardous to human health and, for that reason, must not be drunk.

One method to determine the concentration of $Ni^{2+}_{(aq)}$ ions in drinking water is through by titrating with an EDTA solution, in the presence of the indicator xylenol orange.

In a laboratory, the concentration of $Ni^{2+}_{(aq)}$ ions in the creek water was determined through the following steps:

**א.** i 25 mL of an $EDTA_{(aq)}$ solution with a concentration of 0.001 M were added to a 25-mL sample of creek water. An excess amount of $EDTA_{(aq)}$ solution was used, so that all of the $Ni^{2+}_{(aq)}$ ions would react to form an ion complex, as shown below:

$Ni^{2+}_{(aq)} + EDTA_{(aq)} \longrightarrow Ni(EDTA)^{2+}_{(aq)}$

Calculate the number of mols of EDTA in the 25 mL of $EDTA_{(aq)}$ solution. Show detailed calculations.

ii After the $EDTA_{(aq)}$ was added to the sample, the indicator xylenol orange was added to the obtained solution.

The color of the solution changed to red.

The excess $EDTA_{(aq)}$ was titrated with a 0.001 M solution of zinc ions, $Zn^{2+}_{(aq)}$.

$Zn^{2+}_{(aq)}$ ions and EDTA form the complex $Zn(EDTA)^{2+}_{(aq)}$.

The end point of the titration was determined by a change in the color of the solution, from red to yellow.

The titration required 22 mL of $Zn^{2+}_{(aq)}$ solution.

Calculate the number of mols of $Zn^{2+}_{(aq)}$ ions in the 22 mL of solution. Show detailed calculations.

**ב.** i In order to determine the number of mols of $Ni^{2+}_{(aq)}$ ions in the sample, we need to subtract the number of mols of $Zn^{2+}_{(aq)}$ ions from the number of mols of EDTA that were added to the sample of creek water.

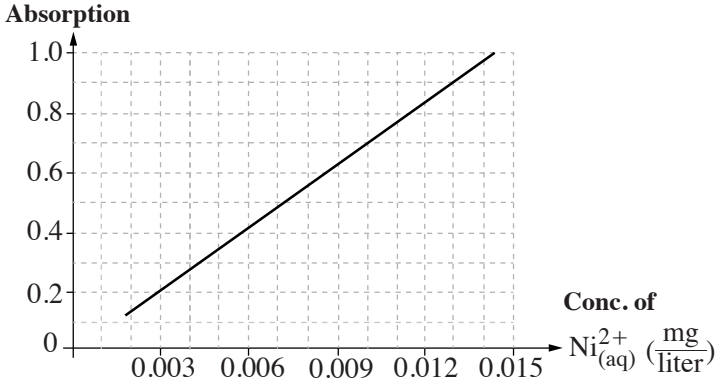
Calculate the molar concentration of $Ni^{2+}_{(aq)}$ ions in the sample. Show detailed calculations.

ii Calculate the concentration of $Ni^{2+}_{(aq)}$ ions in the sample in ppm. Show detailed calculations.

/Continued on page 29/

**ג.** After the creek water was decontaminated, the researchers decided to check the concentration of $Ni^{2+}_{(aq)}$ ions in the water using spectrophotometry instead of titration. Explain why.

The calibration curve presented below shows the relationship between the absorption of solutions that contain $Ni^{2+}_{(aq)}$ ions and the concentration of $Ni^{2+}_{(aq)}$ ions in those solutions. All of the measurements were taken at a constant wavelength of 232 nm.




**ד.** The absorption of a solution in which the concentration of $Ni^{2+}_{(aq)}$ ions is $0.012\frac{mg}{liter}$ is greater than the absorption of a solution in which the concentration of $Ni^{2+}_{(aq)}$ ions is $0.006\frac{mg}{liter}$. Explain why.

**ה.** After the creek had been decontaminated, two water samples, (1)-(2), were collected from two spots along the creek.

i When Sample (1) was examined, an absorption of 0.9 was measured.

Determine the concentration of $Ni^{2+}_{(aq)}$ ions in Sample (1).

iii The concentration of $Ni^{2+}_{(aq)}$ ions in Sample (2) was less than $0.001\frac{mg}{liter}$. In this case, it is impossible to make direct use of the given calibration curve.

What can be done in the laboratory to determine the concentration of $Ni^{2+}_{(aq)}$ ions in Sample (2)?

/Continued on page 30/

**14.** This question concerns greenhouse gases.

**א.** Determine whether <u>each</u> of the statements below, i-iii, is true or false.
<u>Explain each of your answers</u>.

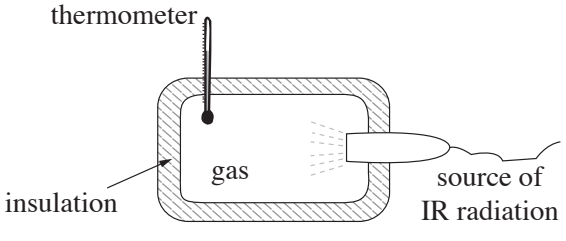
i Greenhouse gases absorb only radiation that reaches them directly from the sun.

ii Without greenhouse gases, the temperature of the Earth would be too low to support life as we know it today.

iii All of the radiation that is emitted from the Earth passes through the atmosphere and into outer space.

**ב.** The greenhouse effect is affected by processes that involve humans.
What is one example of such a process?

Researchers examined the effect of the frequency of infrared (IR) radiation that is absorbed by greenhouse gases on the temperature of those gases.
They carried out an experiment involving three greenhouse gases, which were in identical containers that were sealed and insulated.
The number of mols of gas was the same in <u>each</u> container. <u>Each</u> container of gas was treated with three different frequencies of IR radiation, for a period of 20 minutes.
For each test, the researchers measured the initial temperature and the final temperature of the gas in the sealed, insulated container.
An illustration of the experimental system is shown below.




/Continued on page 31/

The measured gas temperatures, T, are presented in the table below.

| $3.9 \cdot 10^{13}$ | $3.1 \cdot 10^{13}$ | $2.0 \cdot 10^{13}$ | **Frequency of radiation** (HZ) / **Treated greenhouse gas** |
|---|---|---|---|
| **increase in T** | no change in T | no change in T | methane, $CH_{4(g)}$ |
| no change in T | **increase in T** | no change in T | ozone, $O_{3(g)}$ |
| no change in T | no change in T | **increase in T** | carbon monoxide, $CO_{2(g)}$ |

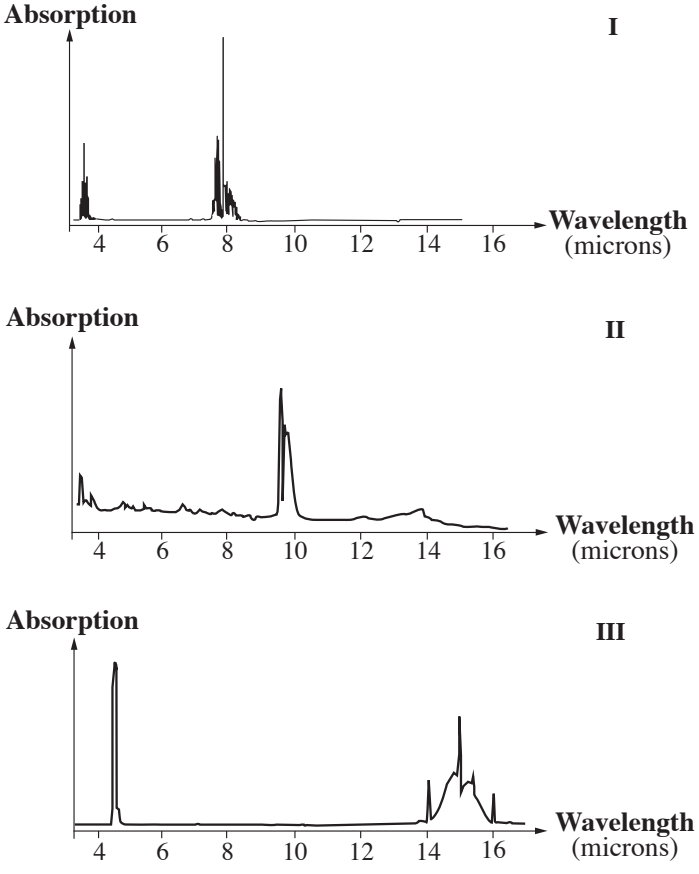
**ג.** i Which of the three gases examined in the experiment absorbed radiation that had the greatest photon energy?
Explain without doing any calculations.

ii The researchers performed an additional test in which they doubled the number of mols of ozone, $O_{3(g)}$, in the container and exposed that $O_{3(g)}$ to IR radiation with a frequency of $3.9 \cdot 10^{13}$ for 20 minutes.
Did doubling the number of mols of $O_{3(g)}$ lead to an increase in the temperature of the gas?
If it did, explain how.
If it did not, explain why.

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

/Continued on page 32/

**ז.** Here are three absorption spectra, I-III, for the 2-16 micron range, for three greenhouse gases: $CO_{2(g)}$, $CH_{4(g)}$ and $O_{3(g)}$.
Which spectrum corresponds to <u>each</u> of the three gases?
<u>Show detailed calculations and explain your answers</u>.




/Continued on page 33/

## Seventh Topic – Topics in Thermodynamics (2)

**Note: Make sure that all equations are balanced and that units are written correctly.**

**15.** Three reactions are shown below, (1)-(3).

(1) $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(\ell)} \quad \Delta H_1^o = -571.6 \text{ kJ}$

(2) $2H_{2(\ell)} + O_{2(\ell)} \rightarrow 2H_2O_{(g)} \quad \Delta H_2^o < 0$

(3) $2H_2O_{(\ell)} \rightarrow 2H_{2(g)} + O_{2(g)} \quad \Delta H_3^o$

**א.** Reaction (1) is carried out in a syringe-shaped, sealed container, at a constant pressure and a constant temperature.

i In Reaction (1), in what direction is energy transferred as work, w? Explain.

ii For Reaction (1), calculate the amount of energy that is transferred as work, w, at 298 K.
Show detailed calculations.

iii Calculate the change in standard internal energy, $\Delta U^o$, for Reaction (1) at 298 K.
Show detailed calculations.

iv What is the value of $\Delta H_3^o$? Explain.

**ב.** Reaction (2) supplies energy to space shuttles as they blast off on their journeys to orbit Earth.
This lift-off requires a tank of liquid oxygen, $O_{2(\ell)}$.
This liquid oxygen has a mass of $6.24 \cdot 10^5$ kg.
Calculate what the volume of the tank needs to be, if we are using oxygen gas, $O_{2(g)}$ at a temperature of 298 K and a pressure of 1 atmosphere. Show detailed calculations.

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

/Continued on page 34/

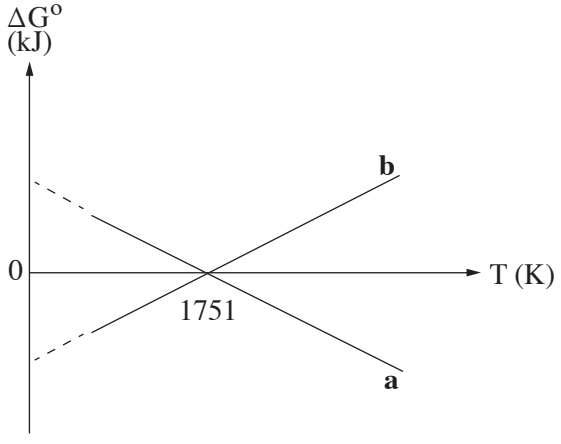
**ג.** The table below shows standard molar entropy values, S°, of substances involved in Reactions (1)-(3).

| $H_2O_{(g)}$ | $H_2O_{(\ell)}$ | $O_{2(g)}$ | $H_{2(g)}$ | **Substance** |
|---|---|---|---|---|
| 188.7 | 70.0 | 205.1 | 130.6 | **Standard molar entropy, S° ($J \cdot K^{-1} \cdot mol^{-1}$)** |

i Explain why the standard molar entropy value, S°, of $H_2O_{(g)}$ is higher than the standard molar entropy value, S°, of $H_2O_{(\ell)}$.

ii Calculate the change in the standard molar entropy of the system, $\Delta S°_{system}$, for Reaction (3). Show detailed calculations.

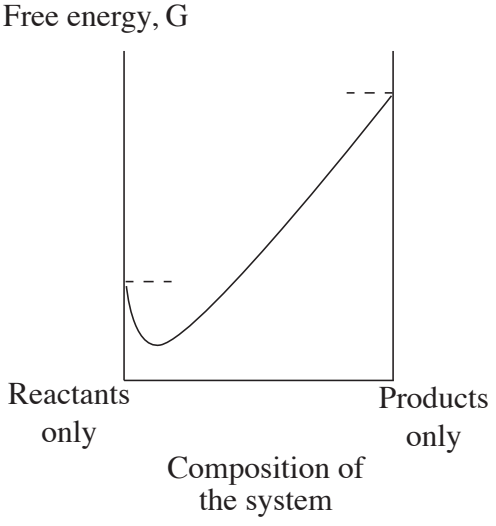
**ד.** The graph below shows two curves, **a** and **b**, which describe the change in standard free energy, $\Delta G°$, as a function of temperature, T, for Reactions (1) and (3).




Which curve corresponds to Reaction (3): **a** or **b**? Explain.

/Continued on page 35/

**ה.** The graph below describes free energy, G, as a function of the composition of the system for <u>one</u> of the reactions, (1) or (3), at a fixed temperature.




Determine which one of the three statements below, I-III, is correct. <u>Explain your answer</u>.

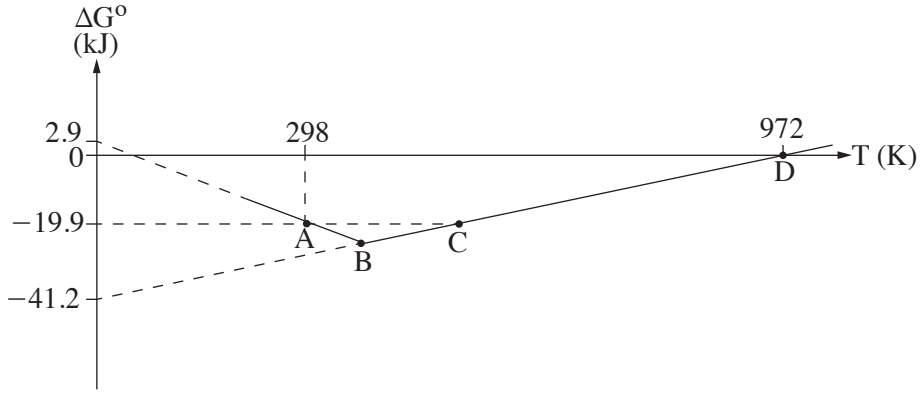
I The graph corresponds to the system of Reaction (1) at 298 K.

II The graph corresponds to the system of Reaction (3) at 298 K.

III The graph corresponds to the system of Reaction (3) at 2000 K.

/Continued on page 36/

**16.** The graph below shows the change in standard free energy, $\Delta G°$, as a function of temperature, T, for the reaction between water and carbon monoxide.




**א.** One of two sections of the graph, AB or BD, corresponds to the following reaction:

$$H_2O_{(\ell)} + CO_{(g)} \rightarrow H_{2(g)} + CO_{2(g)}$$

i Which section, AB or BD, corresponds to the given reaction? Explain.

ii Explain why the slope of the curve changes at Point B.

iii Write the equation for the reaction that corresponds to the other section of the graph (the section you did not choose as your answer for Sub-item א i).

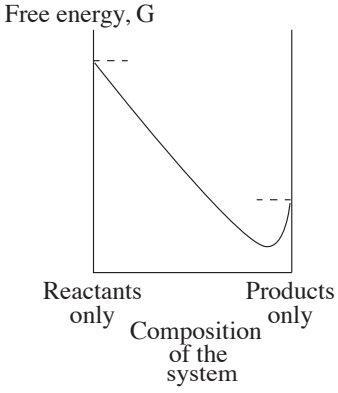
**ב.** i Calculate the change in the standard molar entropy of the system, $\Delta S°_{system}$, for the reaction that corresponds to Section AB of the graph. Show detailed calculations.

ii Calculate the $\Delta S°_{system}$ for the reaction that corresponds to Section BD of the graph. Show detailed calculations.

**ג.** The value of $\Delta G°$ at Point C is equal to the value of $\Delta G°$ at Point A.
The value of the equilibrium constant, K, for the system at the temperature that corresponds to Point C is $K = 1.23 \cdot 10^2$.
Is the value of K for the system at Point A equal to $1.23 \cdot 10^2$ or different from $1.23 \cdot 10^2$? Explain.

/Continued on page 37/

**ד.** The graph below describes free energy, G, as a function of the composition of the system for the given reaction at a temperature of 298 K.




Determine whether each of the statements below, i-ii, is true or false. Explain each of your answers.

i From the graph, we can conclude that the reaction is spontaneous at every temperature.

ii From the graph, we can conclude that at 298 K, the equilibrium constant $K > 1$.

**Good Luck!**



**בהצלחה!**