

Hello, I am Mr. Shadi Hijazi

I'm a chemistry instructor

This is a sample exam that I've prepared for my students in Omega App .

This exam is for LS and GS students of grade 12.



1. The Exam page [2](#)
2. The Answer key page [6](#)
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1. The Exam

The Following Exam is Composed of Three Exercises Inscribed on Four Pages.
Answer the Following Three Exercises

Exercise 1 (7 points)

Esterification Reaction

Esters have agreeable odors while carboxylic acids don't. Esters of low molecular weight are used as fragrances.

The aim of this exercise is to study the lab synthesis of an ester.

Given:

- The molar mass in g.mol⁻¹ of: M(C) = 12, M(H) = 1, and M(O) = 16.
- Ester (E) is produced in the laboratory by the esterification reaction occurring between an alcohol (A) and a carboxylic acid (B).
- Carboxylic acid (B) is pure ethanoic acid.
- Alcohol (A) is monofunctional with saturated non-cyclic carbon chain.

1. Identifying the Alcohol (A) and the Carboxylic acid (B)

Available in the laboratory two flasks (F₁) and (F₂) each containing a colorless liquid. One of the flasks contains the carboxylic acid (B) and the other one contains the alcohol (A) of molecular formula C₄H₁₀O.

The following experiments are performed in order to identify the content of each flask.

- **Experiment 1:** The pH of an aqueous solution that is prepared from flask (F₁) gives value that is strictly less 7.
- **Experiment 2:** The mild oxidation of a sample of flask (F₂) with acidified potassium permanganate (K⁺ + MnO₄⁻) produces a ketone (J).

Document-1

- 1.1. Show that experiment 1 is enough to specify the flask containing compound (A) and the flask containing compound (B).
- 1.2. Based on the experiment 2, deduce the class of the alcohol (A).
- 1.3. Indicate the number of carbon atoms in a molecule of ketone (J). Justify the answer.
- 1.4. Identify the compound (A).
- 1.5. The alcohol (A) is chiral.
 - 1.5.1. Justify its chirality. (LS only)
 - 1.5.2. Represent according to Cram the two enantiomers of this isomer. (LS only)
- 1.6. Draw the condensed structural formula of a positional isomer of (A) and give its systemic name. (GS only)

2. Esterification reaction

0.100 mol of compound (A) is introduced into a round bottom flask containing an equimolar amount of pure ethanoic acid (B), boiling stones, and few drops of concentrated sulfuric acid. The reaction mixture is heated using reflux. Heating stopped at instant t_1 . The number of moles of acid (B) at t_1 is found to be 0.044 mol.

Consider document-2.

For an equimolar mixture of a secondary alcohol and a carboxylic acid, the percentage yield at equilibrium of the esterification reaction is 60%.

Document-2

- 2.1. Write, using condensed structural formulas of organic compounds, the equation of esterification reaction taking place between (A) and (B). Give the name of the ester (E) formed.
- 2.2. This reaction is slow. Pick out from the experimental procedures two indications that verify this affirmation. Justify.
- 2.3. Calculate the yield of this reaction at t_1 .
- 2.4. Deduce whether the instant t_1 represents the time needed by the reaction system to reach equilibrium or not.
- 2.5. Heating is extended to a duration t_2 ($t_2 > t_1$). Specify whether the percentage yield will increase, decrease or remains constant.

Exercise 2 (6 points)

Study of a Drain Opener

A drain opener is a chemical product that unblocks sewer pipes or clogged wastewater drains. Drain openers can either be of acidic or basic nature.

The aim of this exercise is to prepare an acidic solution and use it to verify the label of a drain opener.

Given:

- The experiment is performed at temperature $T = 25^{\circ}\text{C}$.
- $\text{pkw} = 14$ at temperature $T = 25^{\circ}\text{C}$ where kw is the ion product of water.

1. Preparation of the Acidic Solution

Hydrogen chloride HCl gas is dissolved in distilled water to obtain an aqueous hydrochloric acid ($\text{H}_3\text{O}^+ + \text{Cl}^-$) solution (S) of molar concentration $\text{Ca} = 0.05 \text{ mol.L}^{-1}$.

A sample of 20 mL of (S) is used to measure the pH of the solution. The pH of this sample is found to be 1.301.

- 1.1. Show that HCl is a strong acid.
- 1.2. Write the dissociation equation of hydrogen chloride HCl in water.
- 1.3. Calculate the molar concentration of the hydroxide ion (HO^-) in the solution (S).

2. Verification of the label of the drain opener

Document 1 shows the label of a bottle of a drain opener consisting of sodium hydroxide ($\text{Na}^+ \text{HO}^-$) base. This solution is denoted by (S_0).

- ✓ This product is corrosive.
- ✓ The molar mass of NaOH is $M(\text{NaOH}) = 40 \text{ g.mol}^{-1}$.
- ✓ The percentage by mass of NaOH in this product is 29%
- ✓ The density of the solution $d = 1.23 \text{ g. mL}^{-1}$

Document-1

The solution (S_0) is diluted 100 times to obtain a solution (S_1). The pH of (S_1) is 12.95. To verify the label on the bottle, a volume $V_b = 10.0 \text{ mL}$ of solution (S_1) is titrated with hydrochloric acid solution ($\text{H}_3\text{O}^+, \text{Cl}^-$) of molar concentration $C_a = 0.05 \text{ mol. L}^{-1}$ in the presence of a suitable colored indicator. Equivalence point is reached when $V_{aE} = 16.6 \text{ mL}$ of the acid are added.

2.1. Indicate the glassware used to:

- 2.1.1. Transfer the 10 mL of solution (S_1).
- 2.1.2. Add the progressively the hydrochloric acid solution.

2.2. Write the equation of the titration reaction.

2.3. Determine the concentration of solution (S_0).

2.4. Deduce whether the label of the drain opener is validated or not.

3. Using pH-metric Titration:

This titration was carried out using a pH meter instead of the colored indicator.

Draw the shape of the curve $\text{pH} = f(V_a)$ by using the remarkable points of abscissa $V_a = 0 \text{ mL}$ and $V_{aE} = 16.6 \text{ mL}$.

Consider the following scale:

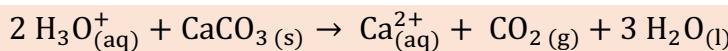
- On the abscissa: 1 cm for 2mL
- On the ordinate: 1 cm for 1 pH unit

Exercise 3: (7 points)

Chemical kinetics

The aim of this exercise is to study the kinetics of the chemical reaction occurring between a strong acid hydrochloric acid ($\text{H}_3\text{O}^+ + \text{Cl}^-$) and limestone CaCO_3 .

The equation of the slow and complete chemical reaction is as follows:



Given:

- $M(\text{CaCO}_3) = 100 \text{ g.mol}^{-1}$ and $M(\text{CO}_2) = 44 \text{ g .mol}^{-1}$
- Carbon dioxide (CO_2) gas is practically insoluble in water.
- The ions of calcium chloride ($\text{Ca}^{2+} + 2 \text{Cl}^-$) don't have any acidic or basic character.

The following experiment is performed.

- A volume $V_a = 10$ mL of hydrochloric acid solution ($H_3O^+ + Cl^-$) of molar concentration $C_a = 1.0 \text{ mol.L}^{-1}$ is poured into an Erlenmeyer flask.
- This flask is then placed on a precision balance and kept unsealed.
- At $t = 0$, a piece of lime stone calcium carbonate $CaCO_3$ of mass m (in grams) is introduced into the unsealed Erlenmeyer flask.
- After a short time, gas bubbles are observed.
- As time passes, the precision balance's display shows a decrease in mass.
- During this chemical reaction, the variation in mass Δm (in grams) is noted, which practically represents the mass of carbon dioxide gas (CO_2) released at any time t .

1. Preliminary study:

- 1.1. Determine the mass of calcium carbonate that must be added at $t = 0$ min to neutralize the acidic solution and thus making the pH of the solution in the Erlenmeyer flask equals to 7.
- 1.2. Explain why the balance shows a decrease in mass over time.
- 1.3. Show that the molar concentration of hydronium ions H_3O^+ remaining at a time t $[H_3O^+]_t$ (expressed in mol.L^{-1}) and the variation in mass Δm (expressed in g) at the same instant t are related by the relation following: $[H_3O^+]_t = 1 - 4.54\Delta m$.

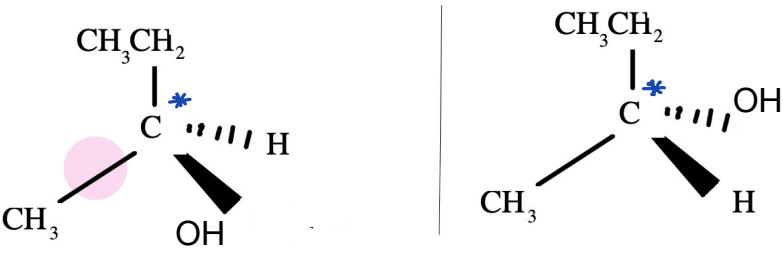
2. Kinetic study.

The table below shows the variation of the molar concentration of hydronium ions remaining at any time t :

| | | | | | | |
|---------------------------------|------|-----|-----|------|------|------|
| Time (sec) | 40 | 80 | 120 | 160 | 200 | 240 |
| $[H_3O^+] (\text{ mol.L}^{-1})$ | 0.75 | 0.6 | 0.5 | 0.45 | 0.42 | 0.39 |
| Document-1 | | | | | | |

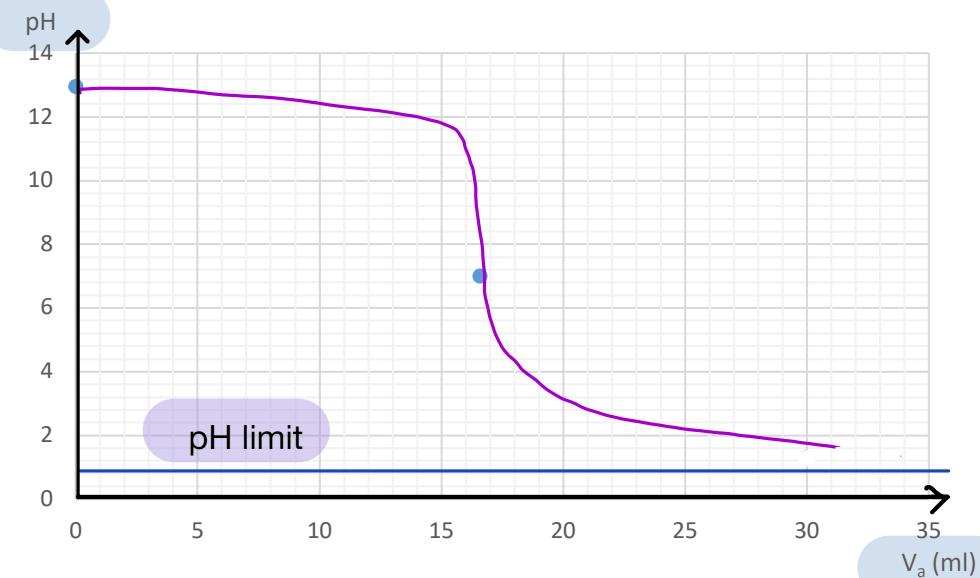
- 2.1. Plot the curve $[H_3O^+] = f(t)$ that studies the variation of the molar concentration of the hydronium ion as a function of time.
Use the following scale:
On the abscissa: 1 cm \leftrightarrow 40 sec and
On the ordinate: 1 cm \leftrightarrow 0.1 mol.L^{-1}
- 2.2. Compare the rate of disappearance of the hydronium ion H_3O^+ to the rate of the chemical reaction at same instant t .
- 2.3. Explain, graphically, the variation in the rate of disappearance of H_3O^+ ions as a function of time.
- 2.4. Specify the kinetic factor responsible for this variation in the rate of the reaction.
- 2.5. Determine the half-life time.

2. The Answer Key

| Exercise 1: organic Chemistry (6 points) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|------------|-------|------------------|---|------------------|---------------------|-----|-----|---|---|--------|-----|-----|---|---|-------------------------|---------|---------|---|---|---|-------|-------|-------|-------|----------|
| Part of the Q | Answer | Mark | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.1. | The pH of an aqueous solution prepared from flask (F ₁) is less than 7, the organic compound in this flask has an acidic character. So, the organic compound in flask (F ₁) is carboxylic acid ethanoic acid. Then, the alcohol is in the flask (F ₂). | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.2. | Alcohol (A) undergoes mild oxidation with potassium permanganate to produce a ketone so (A) is a secondary alcohol. | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.3. | Alcohol (A) contains 4 Carbon atoms. Mild oxidation conserves the C chain so (J) will also contain 4 Carbon atoms per molecule. | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.4. | CH ₃ -CHOH-CH ₂ -CH ₃ (0.25 point) 2-butanol (0.25 point) | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.5.1. | For LS only 2- butanol contains an asymmetric carbon that is surrounded by four different groups (H , OH, CH ₃ , and CH ₃ CH ₂) so it is chiral. | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.5.1. | For LS only  | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.6. | This can be solved by LS but Include the grades only for GS CH ₃ -CH ₂ -CH ₂ -CH ₂ OH (0.5 point). 1-butanol (0.5 point) | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.1. | The equation of the reaction is: $\text{CH}_3 - \text{CHOH} - \text{CH}_2 - \text{CH}_3 + \text{CH}_3 - \text{COOH} \rightleftharpoons \underset{\substack{\parallel \\ \text{O}}}{\text{CH}_3} - \underset{\substack{ \\ \text{CH}_3}}{\text{C}} - \text{O} - \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2\text{O}$ The systematic name of the ester is: 1-methylpropylethanoate Equation (0.5 point). Name (0.5 point) | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.2. | 1- heating by reflux. Temperature is a kinetic factor that increases the rate. (0.5 point) 2- Use of few drops of concentrated sulfuric acid. Catalyst is a kinetic factor that increases the rate. (0.5 point) | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.3. | <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left;">Species</th> <th style="text-align: center;">A</th> <th style="text-align: center;">B</th> <th style="text-align: center;">D</th> <th style="text-align: center;">H₂O</th> </tr> </thead> <tbody> <tr> <td>Initial State (mol)</td> <td style="text-align: center;">0.1</td> <td style="text-align: center;">0.1</td> <td style="text-align: center;">0</td> <td style="text-align: center;">0</td> </tr> <tr> <td>Change</td> <td style="text-align: center;">- x</td> <td style="text-align: center;">- x</td> <td style="text-align: center;">x</td> <td style="text-align: center;">x</td> </tr> <tr> <td>At t₁ (mol)</td> <td style="text-align: center;">0.1 - x</td> <td style="text-align: center;">0.1 - x</td> <td style="text-align: center;">x</td> <td style="text-align: center;">x</td> </tr> <tr> <td>Composition of the system at t₁ (mol)</td> <td style="text-align: center;">0.044</td> <td style="text-align: center;">0.044</td> <td style="text-align: center;">0.056</td> <td style="text-align: center;">0.056</td> </tr> </tbody> </table> <p>n(B) remained at t₁ = 0.1 - x = 0.044 then x = 0.056 mol (0.25 point)</p> | Species | A | B | D | H ₂ O | Initial State (mol) | 0.1 | 0.1 | 0 | 0 | Change | - x | - x | x | x | At t ₁ (mol) | 0.1 - x | 0.1 - x | x | x | Composition of the system at t ₁ (mol) | 0.044 | 0.044 | 0.056 | 0.056 | 1 |
| Species | A | B | D | H ₂ O | | | | | | | | | | | | | | | | | | | | | | | |
| Initial State (mol) | 0.1 | 0.1 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | |
| Change | - x | - x | x | x | | | | | | | | | | | | | | | | | | | | | | | |
| At t ₁ (mol) | 0.1 - x | 0.1 - x | x | x | | | | | | | | | | | | | | | | | | | | | | | |
| Composition of the system at t ₁ (mol) | 0.044 | 0.044 | 0.056 | 0.056 | | | | | | | | | | | | | | | | | | | | | | | |

| | | |
|------|---|-----|
| | <p>$\% \text{yield} = \frac{n(E)_{\text{actual}}}{n(E)_{\text{theoretical}}} \times 100$</p> <p>Finding $n(E)_{\text{theoretical}}$</p> <p>Suppose that this reaction is complete</p> $R(A) = \frac{n_0(A)}{1} = 0.1$ $R(B) = \frac{n_0(B)}{1} = 0.1$ <p>Since $R(A) = R(B)$ the reaction mixture is stoichiometric.</p> <p>According to stoichiometric ratio: $\frac{n_{\text{reacted}}(A)^\infty}{1} = \frac{n_{\text{produced}}(E)^\infty}{1}$</p> <p>$n(A)_r^\infty = n_0(A) = n_{\text{ester(p)}}^\infty = 0.1 \text{ mol}$ (0.5 point)</p> <p>Finding $n(E)_{\text{actual}}$</p> <p>From table of progress $n(E)_{\text{actual}} = 0.056 \text{ mol}$</p> $\% \text{yield} = \frac{0.056}{0.1} \times 100 = 56\%$ (0.25 point) | |
| 2.4. | For an equimolar mixture of a secondary alcohol and a carboxylic acid, the percentage yield at equilibrium is 60%. But % yield at $t_1 < 60\%$ so equilibrium state is not reached at t_1 . | 0.5 |
| 2.5. | Since at t_1 equilibrium state is not reached so heating the reaction mixture will increases number of moles of ester formed before equilibrium till equilibrium state is reached. Then % yield will increase. | 0.5 |

| Exercise 2 (6 points) | | Study of a Drain Opener |
|-----------------------|--|-------------------------|
| Part of Q | Answer | Mark |
| 1.1. | $-\log C_a = -\log 0.05 = 1.301$ $\text{pH(measured)} = 1.301$ Then $\text{pH(measured)} = -\log C_a$ then this acid is a strong acid | 0.5 |
| 1.2. | $\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-$ | 0.5 |
| 1.3. | First Method : $\text{pH} = 14 + \log [\text{HO}^-]$ so $[\text{HO}^-] = 10^{\text{pH}-14} = 10^{1.301-14} = 1.99 \times 10^{-13} \text{ mol. L}^{-1}$ Second Method: $[\text{HO}^-] = \frac{K_w}{[\text{H}_3\text{O}^+]} = \frac{10^{-\text{pKw}}}{C_a} = 1.99 \times 10^{-13} \text{ mol. L}^{-1}$ | 0.5 |
| 2.1.1. | 10 ml volumetric pipet | 0.25 |
| 2.1.2. | Graduated burette | 0.25 |
| 2.2. | $\text{H}_3\text{O}^+ + \text{HO}^- \rightarrow 2\text{H}_2\text{O}$ | 0.75 |
| 2.3. | At equivalence point analyte and titrant reacts in stoichiometric proportions. $\frac{n\text{OH}^-_{\text{present in the flask}}}{1} = \frac{n\text{H}_3\text{O}^+_{\text{added from buret to reach equivalence point}}}{1}$ $C_b V_b = \frac{1}{C_a V_a E}$ $C_b = \frac{C_a V_a E}{V_b} = \frac{0.05 \times 16.6}{10} = 8.3 \times 10^{-2} \text{ mol.L}^{-1}$ (1 point) Upon dilution n(solute) is conserved. $F = \frac{C_o}{C}$ then $C_o = 100 \times 8.3 \times 10^{-2} = 8.3 \text{ mol. L}^{-1}$ (0.5 point) | 1.5 |

| | |
|--|--|
| 2.4. $\%m = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 100 = \frac{n_{\text{solute}} \times M}{d_{\text{solution}} V_{\text{solution}}} \times 100 = \frac{C_0 \times M}{d_{\text{solution}}} \times 100 \quad (0.5 \text{ point})$ $\%m = \frac{8.3 \times 40}{1.23 \times 10^3} \times 100 = 26.99 \% < 29\% \text{ then the label is not valid}$ (0.25 point) | 0.75 |
| Initial point: $V_a = 0 \text{ ml}$, $\text{pH} = 12.95$ Equivalence point: $V_{aE} = 16.6 \text{ ml}$, $\text{pH}_E = 7$ End point: $V_a > V_{aE}$, $\text{pH limit} = -\log C_a = -\log 0.05 = 1.3$ Drawing the shape of the curve.  | 1 |

| Exercise 3: Chemical kinetics (7 points) | | |
|--|--|------|
| Part of the Q | Answer | Mark |
| 1.1. $R(H_3O^+) = \frac{n(H_3O^+)_0}{2}$ $R(CaCO_3) = \frac{n(CaCO_3)_0}{1}$ <p>H_3O^+ is the only acidic species in the reaction mixture. For the solution to be neutralized, the H_3O^+ must react completely. The reaction mixture must be stoichiometric.</p> $R(H_3O^+) = R(CaCO_3)$ $\frac{n(H_3O^+)_0}{2} = \frac{n(CaCO_3)_0}{1}$ $\frac{Ca \times V_a}{2} = \frac{m(CaCO_3)}{M(CaCO_3)}$ $m(CaCO_3) = \frac{1 \times 10 \times 10^{-3} \times 100}{2} = 0.5 \text{ g}$ | 1 | |
| 1.2. <p>As time passes, the amount of CO_2 produced increases. This amount is escaped out of the reaction system since CO_2 is practically insoluble in water. So, the total mass of the flask decreases.</p> | 0.75 | |
| 1.3. <p>According to stoichiometric ratio: $\frac{n(H_3O^+)_r}{2} = \frac{n(CO_2)_t}{1}$ Then $n(H_3O^+)_r = 2 n(CO_2)_t$ But $n(H_3O^+)_t = n(H_3O^+)_0 - n(H_3O^+)_r$ (0.5 point)</p> | 1 | |

| | | |
|------|--|------|
| | <p>Then $n(H_3O^+)t = n(H_3O^+)_0 - 2 n(CO_2)_t$ $[H_3O^+]_t \times V_a = C_a \times V_a - 2 \frac{\Delta m(CO_2)t}{M(CO_2)}$ Divide by V_a $[H_3O^+]_t = C_a - 2 \frac{\Delta m(CO_2)t}{44 \times 10 \times 10^{-3}}$ $[H_3O^+]_t = 1 - 4.54\Delta m.$ (0.5 point)</p> | |
| 2.1. | <i>Graph</i> | 1 |
| 2.2. | <ul style="list-style-type: none"> ▪ According to stoichiometric ratios ▪ $\frac{r(H_3O^+)}{2}$ = rate of reaction (at same t). 0.25 point ▪ $r(H_3O^+) = 2$ rate of reaction <p>$r(H_3O^+) >$ rate of reaction (at same t) 0.25 point</p> | 0.5 |
| 2.3. | <ul style="list-style-type: none"> • The rate of disappearance of reactant is equal to the negative slope of tangent drawn to the curve at t. (0.25 point) • Draw two tangents (T_1) and (T_2) 0.25 point • Negative slope of (T_1) is more than negative slope of (T_2). 0.25 point • As time passes the rate decreases. 0.25 point | 1 |
| 2.4. | <p>The kinetic factor is [reactant] As the reaction proceeds, [reactant] decreases so the rate of disappearance of reactant decreases.</p> | 0.75 |
| 2.5. | <ul style="list-style-type: none"> ▪ Definition: Half-life is the time needed for the concentration of limiting reactant to become equal to half of its initial concentration. 0.25 point ▪ Calculations: At $t_{1/2}$: $[H_3O^+]_{t_{1/2}} = \frac{[H_3O^+]_0}{2} = 0.5 \text{ mol/L}$ 0.25 point ▪ Project on the graph. 0.25 point ▪ Value: from graph $t_{1/2}$ = write value + unit 0.25 point | 1 |