

2021 Fall Semester Midterm Examination For General Chemistry II

Date: Oct 20 (Wed), Time Limit: 19:00 ~ 22:00

NOTICE

- If you have a printer, print the papers and write the answers in the space of each question. If not, prepare several A4-size papers to write only question # and the answers on it in the following example. And for clarity, marking your answer is recommended. Please, print your Student ID in the upper right corner of every page for both of them. (**Handwriting only is acceptable** and typing is not.)

Example:

Professor Name	Class	Student I.D. Number	Name

#1. (a).....

(b).....

- If you have any questions during the period, please contact the TA of your class using the Zoom chat channel to “Everyone” (the only possible choice). Proctors will make any announcements relevant to all students *via* audio.
- While still in the video conference, submit your file to [Midterm Examination], an assignment on Turnitin of your class. **Do not leave the video conference** until your TA is confirmed and tells you that it is fine to leave.

**** This paper consists of 12 sheets with 10 problems (page 11 - 12: Equation, constants & periodic table).** Please check all page numbers before taking the exam. Please write down the unit of your answer when **applicable**. You will get 30% deduction for a value that is missing its unit.

NOTICE: SCHEDULES on RETURN and CLAIM of the MARKED EXAM PAPER.

(채점 답안지 분배 및 이의신청 일정)

1. Period, Location, and Procedure

- 1) Return and Claim Period: **Oct 25 (Mon 12:00~24:00)**
- 2) **Location: Each class of Turnitin site (online)**
- 3) Procedure: If you have any claims on it, email them (Question# and reasons) to your TA.
(The claim is permitted only during the designated claim period. Keep that in mind! A solution file with answers for the examination will be uploaded on the web.)

2. Final Confirmation

- 1) Period: **Oct 28-29 (Thu – Fri)**
- 2) Procedure: During this period, you can check final score of the examination *on the website* again.
(No additional corrections. If no change in your score after reasoning, the claims were not accepted.)

**** For further information, please visit General Chemistry website at www.gencheminkaist.pe.kr**

1. (total 8 pts)

(a) [2 pts] What is the definition of a 'chirality center (chiral center)'? Explain it.

(Answer)

IUPAC full definition: An atom holding a set of ligands in a spatial arrangement which is not superposable on its mirror image. A chirality centre is thus a generalized extension of the concept of the asymmetric carbon atom to central atoms of any element.

Simpler statement: an atom that has all four different groups attached to it

(b) [6 pts] Do the below molecules have the chirality center (at ambient temperature)? Indicate the chirality center and rationalize your answer. R, R', R'', and R''' indicate the different functional groups.

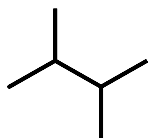
$N+RR'R''R'''$ $CRR'R''R'''$ $PRR'R''$ $NRR'R''$

(Answer)

From the IUPAC definition, $N+RR'R''R'''$, $CRR'R''R'''$, and $PRR'R''$ molecules have the chiral center (N, C, P, each case). However, the N-atom of $NRR'R''$ is not the chiral center as the inversion barriers of amines are typically low (usually 5~10 kcal/mol) and can be overcome at ambient temperatures. In the case of phosphines, the barriers are much higher (> 30 kcal/mol).

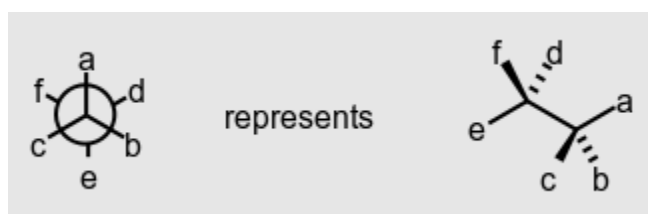
2. (total 12 pts)

(a) [4 pts] Draw two conformational isomers, the gauche form and the anti form of tetramethylethane using the Newman projections as we discussed with ethane and butane in the class.



tetramethylethane

(Newman projection: A projection formula representing the spatial arrangement of bonds on two adjacent atoms in a molecular entity. The structure appears as viewed along the bond between these two atoms, and the bonds from them to other groups are drawn as projections in the plane of the paper. The bonds from the atom nearer to the observer are drawn so as to meet at the centre of a circle representing that atom. Those from the further atom are drawn as if projecting from behind the circle.)

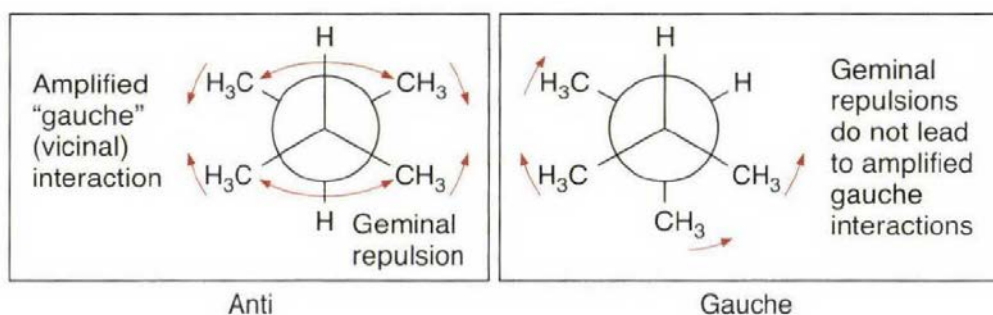


(answer) See the answer of (b).

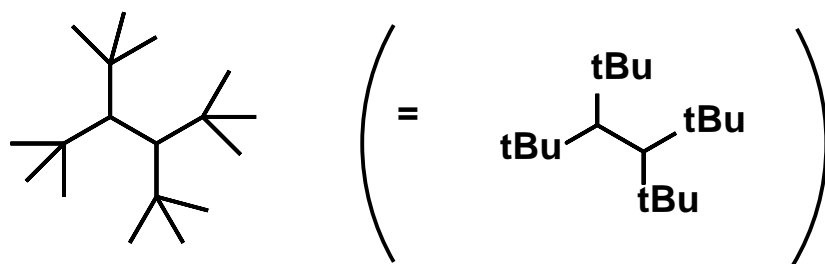
(b) [4 pts] Differently from the butane molecule, it is known that the gauche form is a little more stable than the anti form in the case of tetramethylethane (gauche : anti = 3:2 at 298K). Why do you think it is?

(answer)

From the Newman projection, you can see the $\text{CH}_3\text{-CH}_3$ interaction of the same C (called geminal repulsion) could exist. This geminal repulsion causes expansion of the C-C-C angle, leading to enhanced gauche butane-type interactions in the anti form. In the gauche form, such interaction can be relatively more relieved. (The students do not need to specify the term 'geminal' repulsion. Just conceptual explanation is enough for the credit.)

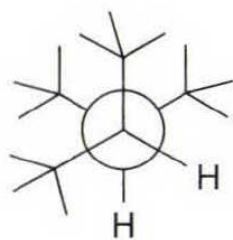


(c) [4 pts] In the case of 1,1,2,2-tetrakis(t-butyl)ethane, the one conformer is dominant at room temperature. Which form do you think is dominant? Rationalize your answer by drawing the Newman projection of the related conformers.



1,1,2,2-tetrakis(*t*-butyl)ethane

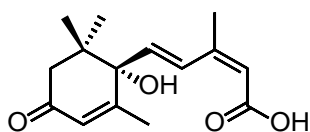
(answer) As discussed in (b), in the case of 1,1,2,2-tetrakis(*t*-butyl)ethane, the increased *t*-butyl maximized the geminal interaction so that the gauche form exists as the dominant form.



1,1,2,2-Tetrakis(*t*-butyl)ethane

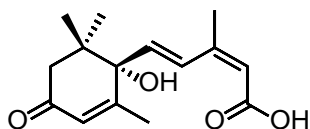
3. (total 10 pts)

Abscisic acid is one kind of plant hormones. The following figure is the structure of abscisic acid.



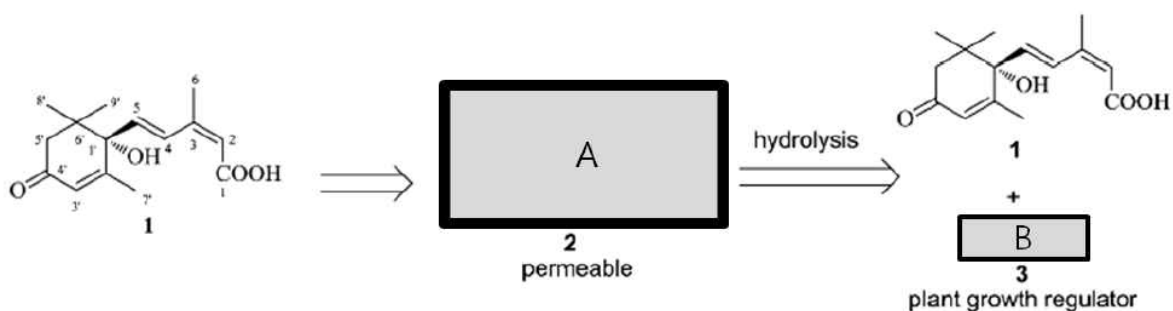
Answer the following questions.

(a) [2 pts] Mark all chiral centers in the following structure.



(b) [2 pts] What is the number of different stereoisomers of abscisic acid?

(c) [4 pts] The given structure above is not permeable for a plant to be used. So, the structure of abscisic acid should be converted into the permeable structure. The process of conversion is described below.

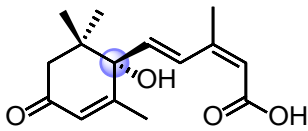


A has an ester group. Let's assume that a net change in the number of atoms is minimum in the reaction to produce **A**. What is the structure of **A** and **B**? **A** and **B** are different compounds. Substitute the unknown structure as R. (Reference: Wan Chaun and others (2015), "Synthesis and biological activity of abscisic acid esters")

(d) [2 pts] In the structure of **A** in problem (c), what is the minimum number of carbon with sp^2 hybridized orbital?

(Answer)

(a) The chiral center includes different four functional groups. So, the chiral center is only one in the abscisic acid like the following figure,



2 pts or 0 pt

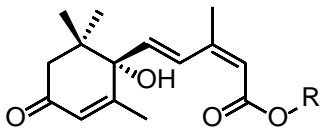
(b) On chiral center: OH and carbon chain can be converted. -> 2 cases

Cis-trans on carbon chain: $2 \times 2 = 4$

The answer is $2 \times 2 \times 2 = 8$

2 pts or 0 pt

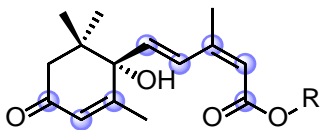
(c) When H is converted to R, the net change of atom's number is minimum. So, the structure of A is same as below.



And when hydrolysis occurs to convert A to original structure, R-OH is emitted. The structure of B is R-OH.

Structure of A: 2 pts, structure of B: 2 pts

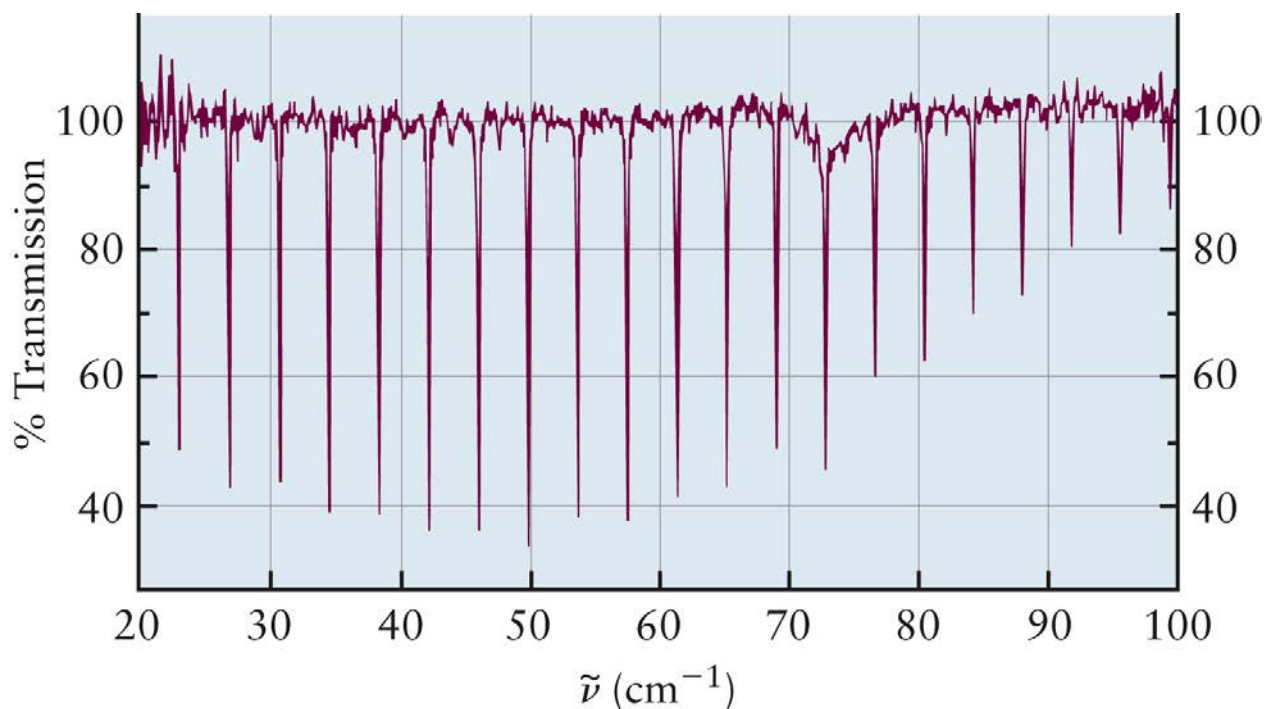
(d) The number of carbon with sp^2 hybridized orbital is same to or more than 8.



2 pts or 0 pt

4. (total 12 pts)

This is a microwave absorption spectrum of gas-phase CO.

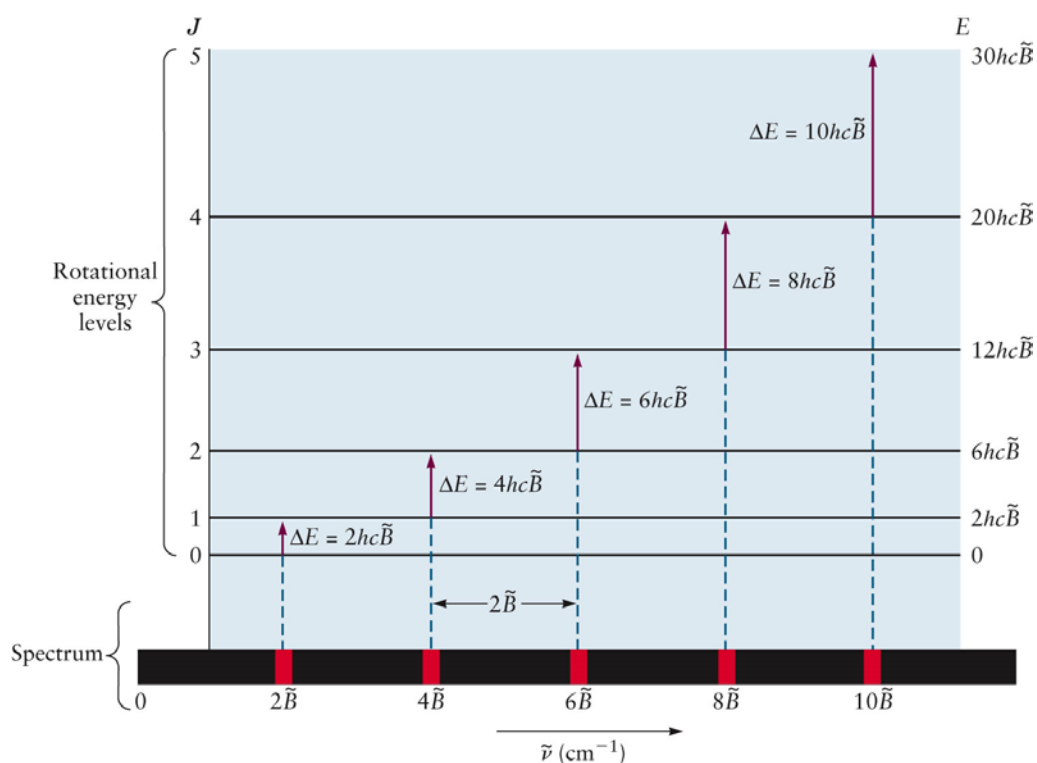


(a) [4 pts] Explain why the peaks are regularly observed in microwave absorption.

(Answer)

Microwave absorption corresponds to rotational transitions. From the selection rule for rotational absorption, the allowed frequencies are indicated as the equations below. By applying this rule to the spectra, the rotational allowed transitions for a heterodiatomic molecule can be predicted to be almost equally spaced ($2\tilde{B}$) wavenumbers.

$$\begin{aligned}\Delta\tilde{\nu} &= \tilde{B}[J_f(J_f + 1) - J_i(J_i + 1)] \\ &= \tilde{B}[(J_i + 1)(J_i + 2) - J_i(J_i + 1)] \\ &= 2\tilde{B}(J + 1)\end{aligned}$$



(b) [8 pts] By analyzing the spectra, please calculate the bond length of CO. (The atomic mass of C and O is 12.01 g/mol and 16.00 g/mol respectively.)

(Answer)

$$2\tilde{B} \approx 30/8 \text{ cm}^{-1} \text{ (from spectra)}$$

$$\tilde{B} \approx \frac{15}{8} \text{ cm}^{-1} \approx 1.875 \times 10^2 \text{ m}^{-1} = \frac{h}{8\pi^2 c I}$$

$$I = \mu R_e^2$$

$$\mu = \frac{m_c m_o}{m_c + m_o} = 1.14 \times 10^{-26} \text{ kg}$$

$$R_e^2 = \frac{h}{8\pi^2 c \mu \tilde{B}} \approx 1.30 \times 10^{-20} \text{ m}^2$$

$$R_e \approx 1.14 \times 10^{-10} \text{ m} \approx 1.14 \text{ \AA}$$

Even if the other value of $2B$ was used, full credits are given as long as the equations and logics are correct

5. (total 8 pts) Answer the following questions.

(a) [2 pts] Describe the vibrational degrees of freedom in linear molecule and nonlinear molecule.

(Answer)

linear molecule: $3N-5$, nonlinear molecule: $3N-6$

(b) [6 pts] Explain the reason why this formula is correct. Explain with the modes of translational, vibrational and rotational mode.

(Answer)

step 1) Find the regularity of the degree of freedom.

In monoatomic molecules, the degrees of freedom is 3. Because it can move to x,y,z axis for three directions.

In diatomic molecules, the degrees of freedom is 6. The diatomic molecule consists of two monoatomic molecules, so we sum up each degrees of freedom together($3+3=6$)

In triatomic molecules, using the same calculation with diatomic molecule, we get 9.

Therefore, we can generalize the degrees of freedom of the molecule which has N atoms as $3N$.

step 2) Calculate the rotational mode and subtract the degrees of freedom in translational mode and rotation mode from total degrees of freedom in all modes.

linear mode:

	linear molecule	nonlinear molecule
translational mode	3	3
vibrational mode	x	y
rotational mode	2	3

$$x=3N-(3+2)=3N-5$$

$$y=3N-(3+3)=3N-6$$

In linear molecule, the degrees of freedom of the rotational mode is 2. Because the rotation centering on the axis doesn't change the energy so it cannot be included in rotation degrees of freedom.

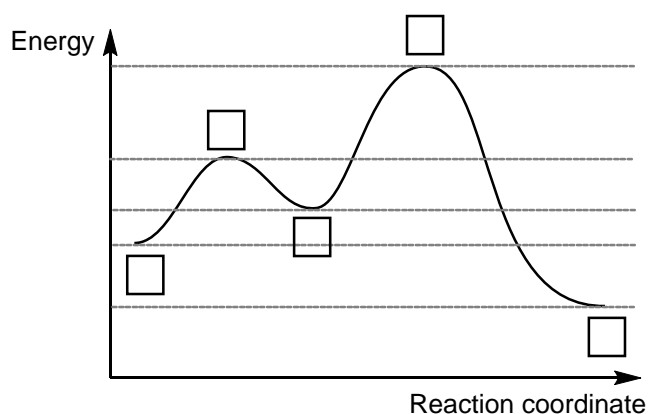
On the contrast, in nonlinear molecule, the axis centered rotation has energy too, so the degrees of freedom should be 3.

What we want to know is the degrees of freedom in vibrational mode, then we have to calculate like below.

(Total degrees of freedom) - (degrees of freedom in translational mode + degrees of freedom in rotational mode)

6. (total 10 pts)

The energy profile for a certain reaction is



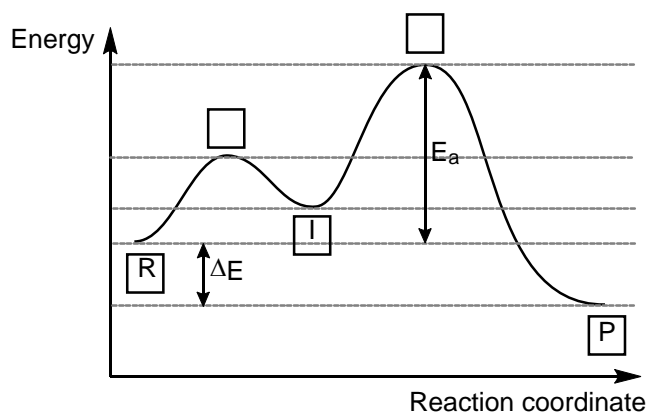
On the energy profile, indicate

(a) [3 pts] The positions of reactant(s) (R), intermediate(s) (I), and product(s) (P).

(b) [2 pts] The activation energy for the overall reaction (E_a).

(c) [2 pts] ΔE for the reaction.

(Answer)



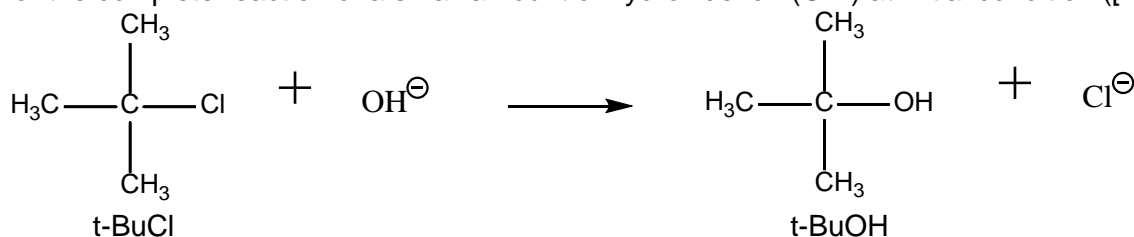
(d) [3 pts] Which step in the mechanism for this reaction is the rate determining step, the first or the second step? Explain the reason including the given keywords.

Keywords: slow, activation energy, rate determining step

(Answer)

In a reaction mechanism, the rate of the slowest step determines the rate of the reaction. The activation energy for the slowest step will be the largest energy barrier that the reaction must overcome. Since the second hump in the diagram is at the highest energy, the second step has the largest activation energy and is the rate determining step (the slow step).

7. (total 12 pts) Conversion of t-butyl chloride (t-BuCl) to t-butyl alcohol (t-BuOH) is a typical example of substitution reaction in organic reactions. The reaction durations were measured at 23°C for the complete reaction of a small amount of hydroxide ion (OH⁻) at initial condition ([M]₀).



Run	[t-BuCl] ₀ (M)	[OH ⁻] ₀ (M)	Time t (sec)	Temp (°C)
1	0.020	0.0040	28	23
2	0.010	0.0040	53	23
3	0.020	0.0020	13	23
4	0.020	0.0040	7	37

a) [4 pts] Use these data to obtain the rate law for this reaction.

(Answer)

The rate law is given in the following form.

$$\text{Rate} = -d[\text{OH}^-]/dt = k [\text{t-BuCl}]^m [\text{OH}^-]^n$$

Initial rate of the reaction (-d[OH⁻]/dt) is calculated as follows.

$$\text{Run 1} - \left\{ \frac{[\text{OH}^-] - [\text{OH}^-]_0}{dt} \right\} = - \left\{ \frac{0.0 - 0.0040}{28} \right\} = 1.43 \times 10^{-4} \text{ M/sec.}$$

Run	[t-BuCl] ₀ (M)	[OH ⁻] ₀ (M)	Time t (sec)	Initial rate -d[OH ⁻]/dt (M/sec)
1	0.020	0.0040	28	1.43 x 10 ⁻⁴
2	0.010	0.0040	53	0.75 x 10 ⁻⁴
3	0.020	0.0020	13	1.54 x 10 ⁻⁴
4	0.020	0.0040	7	5.71 x 10 ⁻⁴

Comparing the data of run 1 and run 2, we see that halving [t-BuCl]₀ halves the rate (m = 1), while the data of run 1 and run 3 show that halving [OH⁻]₀ has almost no effect on the rate (n = 0).

$$\text{Rate} = k [\text{t-BuCl}]$$

(b) [2 pts] Calculate the rate constant at 23 °C.

(Answer)

$$\text{average } k = 7.45 \times 10^{-3} \text{ sec}^{-1}$$

$$(\text{Run 1: } k = 7.15 \times 10^{-3} \text{ sec}^{-1}, \text{ Run 2: } k = 7.5 \times 10^{-3} \text{ sec}^{-1}, \text{ Run 3: } k = 7.7 \times 10^{-3} \text{ sec}^{-1})$$

OR

$$\int_{[t-\text{BuCl}]_0}^{[t-\text{BuCl}]} \frac{d[t-\text{BuCl}]}{[t-\text{BuCl}]} = \int_0^t -k dt$$

$$\ln \frac{[t-\text{BuCl}]}{[t-\text{BuCl}]_0} = -kt$$

$$\text{From Run 1, } [t-\text{BuCl}]_0 = 0.02 \text{ M, } [t-\text{BuCl}] = 0.016 \text{ M, } t = 28; k = 7.97 \times 10^{-3} \text{ sec}^{-1}$$

$$\text{From Run 2, } [t-\text{BuCl}]_0 = 0.01 \text{ M, } [t-\text{BuCl}] = 0.006 \text{ M, } t = 53; k = 9.64 \times 10^{-3} \text{ sec}^{-1}$$

$$\text{From Run 3, } [t-\text{BuCl}]_0 = 0.02 \text{ M, } [t-\text{BuCl}] = 0.018 \text{ M, } t = 13; k = 8.10 \times 10^{-3} \text{ sec}^{-1}$$

$$\text{Average } k = 8.57 \times 10^{-3} \text{ sec}^{-1}$$

(c) [6 pts] When the reaction was carried out at 37°C (Run 4), the measured reaction time was 7 sec. Find the rate constant k at 37 °C and estimate the activation energy E_a and preexponential factor A for this reaction.

(Answer)

Considering $k = 7.45 \times 10^{-3} \text{ sec}^{-1}$

The rate constant k at 37°C is $28.5 \times 10^{-3} \text{ sec}^{-1}$, and from the following equation, ($T_1 = 296\text{K}$) and $T_2 = 310\text{K}$), E_a is 18 kcal/mol.

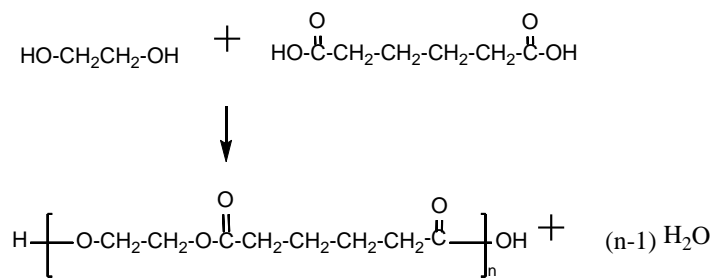
$$\ln k_2 - \ln k_1 = \ln \frac{k_2}{k_1} = -\frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

From Arrhenius equation, $k = A \exp(-E_a/RT)$,
 A is $1.4 \times 10^{11} \text{ sec}^{-1}$.

2 pts each

*** Even if the other value of k is used, full credits are still given if all the logics and equations used are correct.

8. (10 pts) In an acid catalyzed polymerization of ethylene glycol ($[\text{HO-CH}_2\text{-CH}_2\text{-OH}]$ ($[\text{A}]_0 = 1.0 \text{ M}$)) and adipic acid ($[\text{HOOC-(CH}_2)_4\text{-COOH}]$ ($[\text{B}]_0 = 1.0 \text{ M}$)) in equimolar amount at 109 °C, the number average degree of polymerization (DP) of poly(ethylene adipate) product was found to increase from 8 at 1 min to 50 at 300 min. All conditions were held constant, and number average degree of polymerization (DP) X_n is given as follow: $X_n = N_0/N = [\text{A}]_0/[\text{A}] = 1/(1-p)$



a) [5 pts] Determine the rate constant k as defined by:

$$-d[\text{A}]/dt = k [\text{A}] [\text{B}],$$

where the concentrations are in [mol/L] and time t is in [sec].

(Answer)

$$-d[\text{A}]/dt = k [\text{A}] [\text{B}] = k [\text{A}]^2 \text{ (ethylene glycol: A, adipic acid: B, } [\text{A}] = [\text{B}] \text{)}$$

It is a second order reaction.

$$1/[\text{A}] - 1/[\text{A}]_0 = k t$$

$$X_n = 1 + [\text{A}]_0 k t \text{ (because } X_n = N_0/N = [\text{A}]_0/[\text{A}] \text{),}$$

$$X_{n, t_2} - X_{n, t_1} = (1 + [\text{A}]_0 k t_2) - (1 + [\text{A}]_0 k t_1) = [\text{A}]_0 k (t_2 - t_1)$$

$$t_1 = 1 \text{ min, and } t_2 = 300 \text{ min, } (t_2 - t_1) = 300 - 1 = 299 \text{ min} = 17,940 \text{ sec}$$

$$X_{n, t_2} = 50 \text{ and } X_{n, t_1} = 8$$

$$42 = [\text{A}]_0 k 17940 = 17940 k \text{ (} [\text{A}]_0 = 1 \text{ M)}$$

$$k = 2.34 \times 10^{-3} \text{ (L mol}^{-1} \text{ sec}^{-1}\text{)}$$

b) [5 pts] The equilibrium constant $K = \frac{[-\text{COO}^-][\text{H}_2\text{O}]}{[-\text{COOH}][-\text{OH}]}$ is 1 at 109 °C. What molar ratio (Y) of water to carboxylic acid end group concentration ($Y = \frac{[\text{H}_2\text{O}]}{[-\text{COOH}]}$) would lead to an equilibrium value of DP (\bar{X}_n) = 50 at 109 °C?

(Answer)

$$\begin{aligned} K &= \frac{[-\text{COO}^-][\text{H}_2\text{O}]}{[-\text{COOH}][-\text{OH}]} \\ &= Y \frac{[-\text{COO}^-]}{[-\text{OH}]} \quad (\text{because } Y = \frac{[\text{H}_2\text{O}]}{[-\text{COOH}]}) \\ &= Y \left\{ \frac{p[A]_0}{(1-p)[A]_0} \right\} \end{aligned}$$

(because $[-\text{OH}]$ is the concentration of remaining $-\text{OH}$ group, and $[-\text{COO}^-]$ is equal to the concentration of reacted $-\text{OH}$ group at time t)

$$Y = K / \left\{ \frac{p[A]_0}{(1-p)[A]_0} \right\} = K / \left\{ \frac{p}{(1-p)} \right\}$$

(because $K = 1$, and $1/(1-p) = \bar{X}_n = 50$, $p = 0.98$)

$$Y = 1 / \left\{ \frac{0.98}{(1-0.98)} \right\} = 0.02 / 0.98 = 2.04 \times 10^{-2}$$

9. (total 6 pts)

Paraffins and polyethylenes consisting of methylene repeating units have very different molecular weights and show very different mechanical properties. Even though both of them are solids at room temperature, polyethylene is tough while paraffin can be deformed easily. Explain these very different mechanical properties with at least two reasons.

(Answer)

i) Tie molecules (tie polymer chains) in the crystalline region and ii) chain entanglements in the amorphous region of polymers make polymeric materials very strong and tough. (Secondary interaction (van der Waals force) among polyethylene chains is not a major factor).

3 pts for each reason

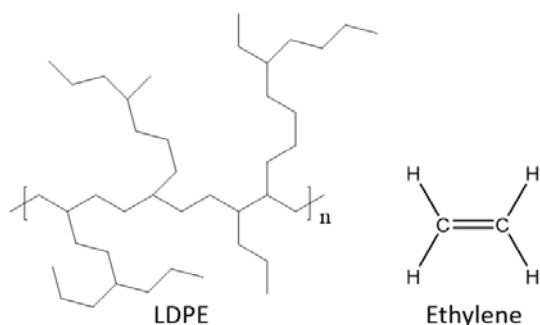
10. (total 12 pts)

a) [8 pts] Draw a representative molecular structure of the following polymers and the corresponding monomer for each polymer.

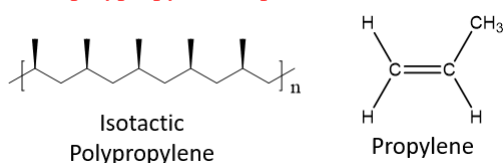
- (1) Low density polyethylene (LDPE)
- (2) Isotactic polypropylene
- (3) Polyethylene terephthalate (PET)
- (4) Poly(hexamethylene adipamide) (nylon 66)

(Answer)

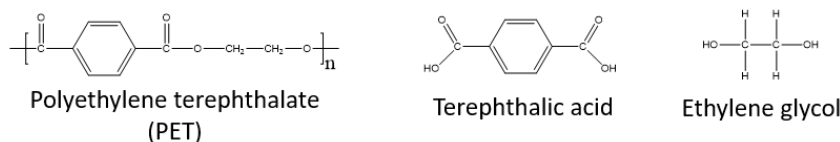
- (1) Low density polyethylene (LDPE) [2 pts]



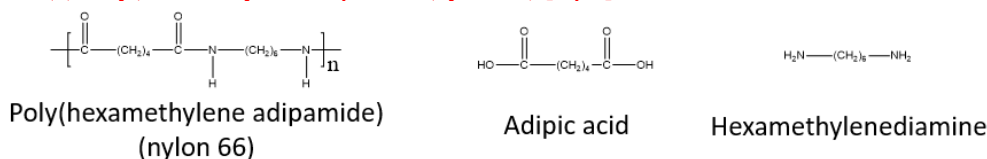
- (2) Isotactic polypropylene [2 pts]



- (3) Polyethylene terephthalate (PET) [2 pts]



- (4) Poly(hexamethylene adipamide) (nylon 66) [2 pts]



b) [4 pts] Describe the difference in the synthesis method of two polymers.

- (1) Low density polyethylene (LDPE) and High density polyethylene (HDPE)
- (2) Polyethylene (PE) and Polyethylene terephthalate (PET)

Answer

(1) Both LDPE and HDPE are synthesized with addition polymerization method. LDPE is synthesized with free-radical-initiated addition polymerization in high temperature and pressure, which introduces heavily branched polyethylene with an imperfect linear chain. In contrast to LDPE,

HDPE is synthesized using a Ziegler catalyst to lower the reaction temperature and pressure. As a result, linear polyethylene with fewer branches is synthesized.

(2) Polyethylene is synthesized with addition polymerization. This polymerization is chain-growth polymerization that proceeds through a free-radical mechanism. The free radical mechanism of addition polymerization is completed by three steps: Initiation, propagation, and termination.

Polyethylene terephthalate is synthesized with condensation polymerization. This polymerization is a step-growth polymerization that proceeds through condensation reaction where monomers join together and lose small molecules as byproducts.

Physical Constants

Avogadro's number	$N_A = 6.02214179 \times 10^{23} \text{ mol}^{-1}$
Bohr radius	$a_0 = 0.52917720859 \text{ \AA} = 5.2917720859 \times 10^{-11} \text{ m}$
Boltzmann's constant	$K_B = 1.3806504 \times 10^{-23} \text{ J K}^{-1}$
Electronic charge	$e = 1.602176487 \times 10^{-19} \text{ C}$
Faraday constant	$F = 96485.3399 \text{ C mol}^{-1}$
Masses of fundamental particles:	
Electron	$m_e = 9.10938215 \times 10^{-31} \text{ kg}$
Proton	$m_P = 1.672621637 \times 10^{-27} \text{ kg}$
Neutron	$m_n = 1.674927211 \times 10^{-27} \text{ kg}$
Permittivity of vacuum	$\epsilon_0 = 8.854187817 \times 10^{-12} \text{ C}^{-2} \text{ J}^{-1} \text{ m}^{-1}$
Planck's constant	$h = 6.62606896 \times 10^{-34} \text{ J s}$
Ratio of proton mass to electron mass	$m_P / m_e = 1836.15267247$
Speed of light in a vacuum	$c = 2.99792458 \times 10^8 \text{ m s}^{-1}$ (exactly)
Standard acceleration of terrestrial gravity	$g = 9.80665 \text{ m s}^{-2}$ (exactly)
Universal gas constant	$R = 8.314472 \text{ J mol}^{-1} \text{ K}^{-1}$ $= 0.0820574 \text{ L atm mol}^{-1} \text{ K}^{-1}$

Values are taken from the 2006 CODATA recommended values, as listed by the National Institute of Standards and Technology.

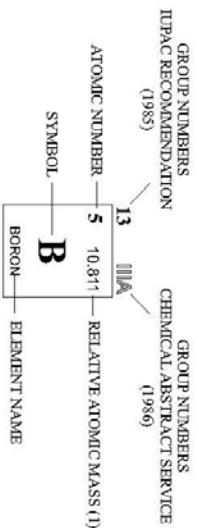
Conversion factors

Ångström	$1 \text{ \AA} = 10^{-10} \text{ m}$
Atomic mass unit	$1 \text{ u} = 1.660538782 \times 10^{-27} \text{ kg}$ $1 \text{ u} = 1.492417830 \times 10^{-10} \text{ J} = 931.494028 \text{ MeV}$ (energy equivalent form $E = mc^2$)
Calorie	$1 \text{ cal} = 4.184 \text{ J}$ (exactly)
Electron volt	$1 \text{ eV} = 1.602177 \times 10^{-19} \text{ J} = 96.485335 \text{ kJ mol}^{-1}$
Foot	$1 \text{ ft} = 12 \text{ in} = 0.3048 \text{ m}$ (exactly)
Gallon (U. S.)	$1 \text{ gallon} = 4 \text{ quarts} = 3.785412 \text{ L}$ (exactly)
Liter	$1 \text{ L} = 10^{-3} \text{ m}^3 = 10^3 \text{ cm}^3$ (exactly)
Liter-atmosphere	$1 \text{ L atm} = 101.325 \text{ J}$ (exactly)
Metric ton	$1 \text{ t} = 1000 \text{ kg}$ (exactly)
Pound	$1 \text{ lb} = 16 \text{ oz} = 0.4539237 \text{ kg}$ (exactly)
Rydberg	$1 \text{ Ry} = 2.17987197 \times 10^{-18} \text{ J} = 1312.7136 \text{ kJ mol}^{-1} = 13.60569193 \text{ eV}$
Standard atmosphere	$1 \text{ atm} = 1.01325 \times 10^5 \text{ Pa} = 1.01325 \times 10^5 \text{ kg m}^{-1} \text{ s}^{-2}$ (exactly)
Torr	$1 \text{ torr} = 133.3224 \text{ Pa}$

PERIODIC TABLE OF THE ELEMENTS

<http://www.kj-soft.com/periodictable/>

GROUP	PERIOD																																															
1	IIA												VIIIA																																			
1	H													2																																		
2	Li	Be											He																																			
3	Na	Mg											Ne																																			
4	K	Ca											Ar																																			
5	Rb	Sr											Kr																																			
6	Cs	Ba											Xe																																			
7	Fr	Ra											Rn																																			
19	39.098	20	40.078	21	44.956	22	47.867	23	50.942	24	51.996	25	54.938	26	55.845	27	58.933	28	58.693	29	63.546	30	65.39	31	69.723	32	72.64	33	74.922	34	78.96	35	79.904	36	83.80													
37	85.468	38	87.62	39	88.906	40	91.224	41	92.906	42	95.94	43	(99)	44	101.07	45	102.91	46	106.42	47	107.87	48	112.41	49	114.82	50	118.71	51	121.76	52	127.60	53	126.90	54	131.29													
55	132.91	56	137.33	57-71	Lanthanide										72	178.49	73	180.95	74	183.84	75	186.21	76	190.23	77	192.22	78	195.08	79	196.97	80	200.59	81	204.38	82	207.2	83	208.98	84	(209)	85	(210)	86	(222)				
87	(223)	88	(226)	89-103	Actinide										104	(261)	105	(262)	106	(266)	107	(264)	108	(277)	109	(268)	110	(281)	111	(272)	112	(285)	113	(284)	114	(289)	115	(288)	116	(292)	117	(293)	118	(294)	119	(293)	120	(293)



LANTHANIDE

57	138.91	58	140.12	59	140.91	60	144.24	61	(145)	62	150.36	63	151.96	64	157.25	65	158.93	66	162.50	67	164.93	68	167.26	69	168.93	70	173.04	71	174.97
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu															
LANTHANUM	CERUM	PRASEODYMIUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLIUM	ERBIUM	THULIUM	YTERBIUM	LUTETIUM															

ACTINIDE

89	(227)	90	232.04	91	231.04	92	238.03	93	(237)	94	(244)	95	(243)	96	(247)	97	(247)	98	(251)	99	(252)	100	(257)	101	(258)	102	(259)	103	(262)
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr															
ACTINIUM	THORIUM	PROTACTINIUM	URANIUM	NEPTUNIUM	PLUTONIUM	AMERICIUM	CURIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MEYERBERGIUM	NOBELIUM	LAWRENCIUM															

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
 Relative atomic mass is shown with the significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.
 However, these such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

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