2013 SPRING Semester Midterm Examination
For General Chemistry I

Date: April 24 (Wed), Time Limit: 7:00 ~ 9:00 p.m.

Write down your information neatly in the space provided below; print your Student ID in the upper right corner of every page.

Professor Name	Class	Student I.D. Number	Name

Problem	points	Problem	points	TOTAL pts
1	/6	**6**	/10	**/100**
2	/10	**7**	/10	
3	/10	**8**	/11	
4	/8	**9**	/11	
5	/9	**10**	/15	

** This paper consists of 13 sheets with 10 problems (page 11 & 12: constants & periodic table, page 13: claim form). Please check all page numbers before taking the exam. Write down your work and answers in the Answer sheet.

Please write down the unit of your answer when applicable. You will get 30% deduction for a missing unit.

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

(채점답안지 분배 및 이의신청 일정)

1. Period, Location, and Procedure

1) Return and Claim Period: ***April 29 (Mon, 6: 30 ~ 7:00 p.m.)***
2) ***Location: Room for quiz session***
3) Procedure:

Rule 1: Students cannot bring their own writing tools into the room. (Use a pen only provided by TA)

Rule 2: With or without claim, you must submit the paper back to TA. (Do not go out of the room with it)

If you have any claims on it, you can submit the claim paper with your opinion. After writing your opinions on the claim form, attach it to your mid-term paper with a stapler. Give them to TA.

(The claim is permitted only on the period. Keep that in mind! A solution file with answers for the examination will be uploaded on 4/27 on the web.)

2. Final Confirmation

1) Period: May 2 (Thu) – 3 (Fri)
2) Procedure: During this period, you can check final score of the examination *on the website* again.

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

1. (6 pts in total) Take note that ionization energies for the 1s element of the second-row atoms are :

Li	4,820	Be	10,600	B	18,300	C	27,000
N	38,600	O	51,000	F	66,600		kJ mol^{-1}

Now suppose that a certain substance is bombarded by X-rays having a wavelength of 0.989 nm. If photoelectrons with kinetic energies of (a) 94,000 kJ mol^{-1} and (b) 69,900 kJ mol^{-1} are ejected from the material, which of the elements listed above must be present in the sample?

(Answer)

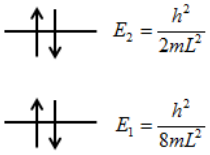
2. (10 pts in total) In the 1D-particle-in-a-box problem, the energy of a particle is given by the formula, $E = n^2h^2/(8mL^2)$ [n = 1, 2, 3, …; L: the length of the box].

(a) What is the energy of a particle, if we extend it to the 2D-particle-in-a-box problem? Each side of the 2D box has the length of L.

(Answer)

(b) Let's try to fill energy levels obtained in (a) with 4 electrons. Assume that though energy levels are not altered by the repulsive potential between electrons, all the other properties of an electron (e.g., Pauli exclusion principle and Hund's rule) should be considered. Draw the ground state electronic configuration as shown in the following example.

Example) In the case of 1D with 4 electrons,

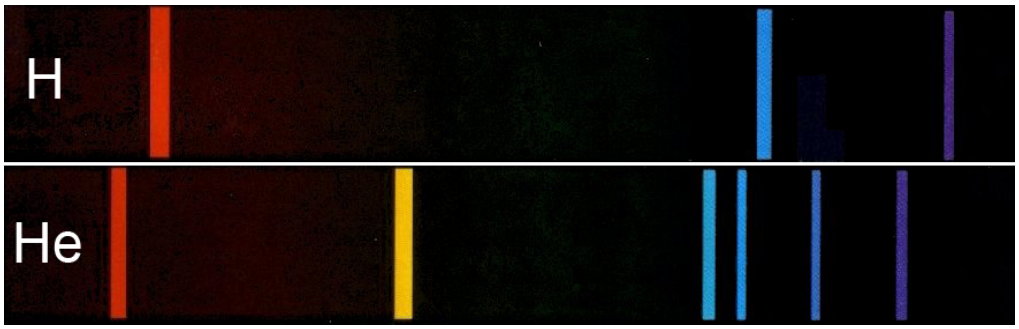


(Answer)

(c) What would be the lowest excitation energy in the case of (b)?

(Answer)

3. (10 pts in total) While the atomic spectrum of hydrogen shows mainly 3 lines in the visible range (420~700 nm), the spectrum of helium shows mainly 6 lines.



(a) Calculate the wavelengths (nm) of three distinct lines of hydrogen and assign them with the orbital energy levels.

(Answer)

(b) Why does the spectrum double the number of lines in helium?

(Answer)

(c) Draw the orbital energy levels of helium based on the above observation.

(Answer)

4. (8 pts in total)

(a) Iridium (Ir) is predicted by the building-up principle to have three unpaired electrons in its ground state outer configuration, but in fact has only one. Write the predicted and actual full electron configurations that explain this fact. You may use short hand noble gas configurations for core electrons.

(Answer)

(b) Write the electron configuration of Sc and Sc^{+}, given that they are both paramagnetic. You may use short hand noble gas configurations for core electrons.

(Answer)

(c) Identify the element of period 2 that possesses the ionization energies (I in kJ mol^{-1}) in the table below.

I_1	I_2	I_3	I_4	I_5	I_6
1090	2350	4610	6220	37800	47000

(Answer)

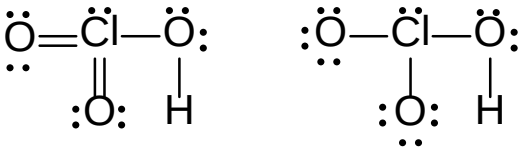
5. (9 pts in total)

(a) In the P_4 molecule, each atom has a complete octet. Figure out the structure of P_4.

(Answer)

Determine the formal charge on each atom in the following molecules. Identify the structure of lower energy in each pair.

(b)



(c)

(d)

6. (10 pts in total)

For each pair, determine which compound has bonds with greater ionic character:

(a) HCl or HI

(b) CH_4 or CF_4

(c) CO_2 or CS_2

(d) Arrange the anions Cl^-, Br^-, N^{3-}, and O^{2-} in order of increasing polarizability and give reasons for your decisions.

7. (10 pts in total) Predict the geometry of the following molecules, using the VSEPR method.

(a) SF_4

(b) BF_3

(c) ClF_3 (Cl = chlorine)

(d) XeF_2

(e) C_2H_2

(f) Acrylonitrile, CH_2CHCN, is used in the synthesis of acrylic fibers (polyacrylonitriles), such as Orlon. Write the Lewis structure of acrylonitrile and describe the hybrid orbitals on each carbon atom. What are the approximate values of the bond angles?

8. (11 pts in total) To explain molecular geometries of a water molecule, H_2O,

(a) Write the electron configurations of H and O atoms.

(Answer)

(b) Use the VSEPR theory to sketch and name the molecular geometry of H_2O.

(Answer)

(c) Use the valence bond (VB) theory to predict the hybridization of atomic orbitals of the oxygen atom. Give the number and name of hybridized orbitals, occupied electrons, and bonding electrons.

(Answer)

(d) How many molecular orbitals (MOs) do we need to explain electron spreading over a water molecule?

(Answer)

9. (11 pts in total)

(a) On the basis of the configuration of the neutral molecule F_2, write the molecular orbital configuration of the valence molecular orbitals for (1) $\mathbf{F_2^-}$; (2) $\mathbf{F_2^+}$; (3) $\mathbf{F_2^{2-}}$.

(b) For each species, give the expected bond order.

(c) Which are paramagnetic, if any?

(d) Is the highest-energy orbital that contains an electron σ or π in character?

10. (15 pts in total)

(a) Suggest two Lewis structures that contribute equally to the resonance structure for sulfur dioxide, SO_2 molecule.

(b) Use a valence bond approach to describe the geometry, hybridization, and bonding.

(c) Construct three molecular orbitals using the p orbitals of O and S atoms perpendicular to the plane of the molecule.

(d) Among the three molecular orbitals, which one is HOMO?

FUNDAMENTAL CONSTANTS

Name	Symbol	Value
Atomic mass constant	m_u	$1.660\,54 \times 10^{-27}$ kg
Avogadro's constant	N_A	$6.022\,14 \times 10^{23}$ mol^{-1}
Boltzmann's constant	k	$1.380\,65 \times 10^{-23}$ J·K^{-1}
Fundamental charge	e	$1.602\,18 \times 10^{-19}$ C
Faraday's constant	$F = N_A e$	$9.648\,53 \times 10^{4}$ C·mol^{-1}
Gas constant	$R = N_A k$	$8.314\,47$ J·K^{-1}·mol^{-1}
		$8.314\,47$ L·kPa·K^{-1}·mol^{-1}
		$8.205\,74 \times 10^{-2}$ L·atm·K^{-1}·mol^{-1}
		$62.36\,37$ L·Torr·K^{-1}·mol^{-1}
		$8.314\,47 \times 10^{-2}$ L·bar·K^{-1}·mol^{-1}
Mass of electron	m_e	$9.109\,38 \times 10^{-31}$ kg
Mass of neutron	m_n	$1.674\,93 \times 10^{-27}$ kg
Mass of proton	m_p	$1.672\,62 \times 10^{-27}$ kg
Planck's constant	h	$6.626\,08 \times 10^{-34}$ J·s
	$\hbar = h/2\pi$	$1.054\,57 \times 10^{-34}$ J·s
Rydberg constant	$\mathcal{R}$	$3.289\,84 \times 10^{15}$ Hz
Speed of light	c	$2.997\,92 \times 10^{8}$ m·s^{-1}
Standard acceleration of free fall	g	$9.806\,65$ m·s^{-2}
Vacuum permittivity	ε_0	$8.854\,19 \times 10^{-12}$ J^{-1}·C^2·m^{-1}

RELATIONS BETWEEN UNITS*

Property	Common unit	SI unit
Mass	2.205 lb (lb = pound)	1.000 kg
	1.000 lb	453.6 g
	1.000 oz (oz = ounce)	28.35 g
	1.000 ton (= 2000 lb)	907.2 kg
	1 t (t = tonne, metric ton)	**10^3 kg**
Length	1.094 yd (yd = yard)	1.000 m
	0.3937 in. (in. = inch)	1.000 cm
	0.6214 mi (mi = mile)	1.000 km
	1 in.	**2.54 cm**
	1 ft (ft = foot)	**30.48 cm**
	1.000 yd	0.9144 m
	1 Å (Å = ångström)	**10^{-10} m**
Volume	**1 L (L = liter)**	**10^3 cm^3, 1 dm^3**
	1.000 gal (gal = gallon)†	3.785 dm^3 (3.785 L)
	1.00 ft^3 (ft^3 = cubic foot)	2.83×10^{-2} m^3 (28.3 L)
	1.00 qt (qt = quart)†	9.46×10^{2} cm^3 (0.946 L)
Time	**1 min (min = minute)**	**60 s**
	1 h (h = hour)	**3600 s**
	1 day	**86 400 s**
Pressure	**1 atm (atm = atmosphere)**	**$1.013\,25 \times 10^5$ Pa**
	1.000 Torr or 1.000 mmHg	133.3 Pa
	1.000 psi (psi = pounds per square inch)	6.895 kPa
	1 bar	**10^5 Pa**
Energy	**1 cal**	**4.184 J**
	1 eV	1.60218×10^{-19} J; 96.485 kJ·mol^{-1}
	1 C·V	**1 J**
	1 kWh (kWh = kilowatt hour)	**3.600×10^3 kJ**
	1 L·atm	**101.325 J**

Temperature conversions	(Fahrenheit temperature)/°F = $\frac{9}{5}$ × (Celsius temperature)/°C + 32
	(Celsius temperature)/°C = $\frac{5}{9}$ + {(Fahrenheit temperature)/°F − 32}
	(Kelvin temperature)/K = (Celsius temperature)/°C + 273.15

*Entries in boldface type are exact.

†The European and Canadian Imperial quart and gallon are 1.201 times as large.

<The Answers>

Problem	points	Problem	points	TOTAL pts
1	3+3/6	**6**	2+2+2+4/10	**/100**
2	3+3+4/10	**7**	1×5+5/10	
3	3+4+3/10	**8**	2+2+4+3/11	
4	3+3+2/8	**9**	5+2+2+2/11	
5	3+2+2+2/9	**10**	3+5+5+2/15	

1. (6 pts in total)

(a) (3 pts)

$$E = h\nu = \frac{hc}{\lambda}$$

part of which plays for ionization (I), while the rest goes into the kinetic energy of the ejected photoelectron.

$$E = I + \frac{1}{2}mv^2$$

$$E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}Js)\,(3.00\times10^{8}ms^{-1})}{0.989\times10^{-9}m} \times \frac{6.02\times10^{2}}{mol}$$

$$= 1.21\times10^{5}kJ/mol$$

$$For\ \ 94{,}000\ kJ/mol$$

$$I = E - \frac{1}{2}mv^2 = (1.21-0.94)\times10^{5}kJ/mol$$

$$= 2.7\times10^{4}kJ/mol$$

attribute to carbon atom

(b) (3 pts)

$$For\ \ 69{,}900\ kJ/mol$$

$$I = E - \frac{1}{2}mv^2 = (1.21-0.699)\times10^{5}kJ/m$$

$$= 5.11\times10^{4}kJ/mol$$

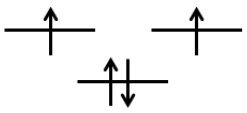
attribute to oxygen atom

2. (10 pts in total)

(a) (3 pts) Hamiltonian for a particle in the 2D box can exactly be decomposed by two independent Hamiltonian for the corresponding 1D problem: $H = H_1 + H_2$. Therefore, the energy of a particle in 2D is simply the sum of energies for the H_1 and H_2. Consequently,

$$E_{n_1,n_2} = \frac{h^2}{8mL^2}\left(n_1^2 + n_2^2\right)$$, where n_1 = 1, 2, 3, … and n_2 = 1, 2, 3, ….

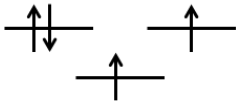
(b) (3 pts)



$$E_{2,1} = E_{1,2} = \frac{5h^2}{8mL^2}$$

$$E_{1,1} = \frac{h^2}{4mL^2}$$

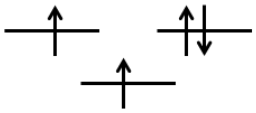
(c) (4 pts)



$$E_{2,1} = E_{1,2} = \frac{5h^2}{8mL^2}$$

$$E_{1,1} = \frac{h^2}{4mL^2}$$

or



$$E_{2,1} = E_{1,2} = \frac{5h^2}{8mL^2}$$

$$E_{1,1} = \frac{h^2}{4mL^2}$$

Excitation energy = $E_{2,1}$(or $E_{1,2}$) – $E_{1,1}$ = **$(3h^2)/(8mL^2)$**

3. (10 pts in total)

(a) (3 pts) $\Delta E = hc/\lambda = -hR(1/n^2 - 1/2^2)$

$\lambda = c/\{R(1/2^2 - 1/n^2)\} = (2.998\times10^8\ ms^{-1})/(3.29\times10^{15}\ s^{-1}) \times 1/(1/n^2 - 1/2^2)$

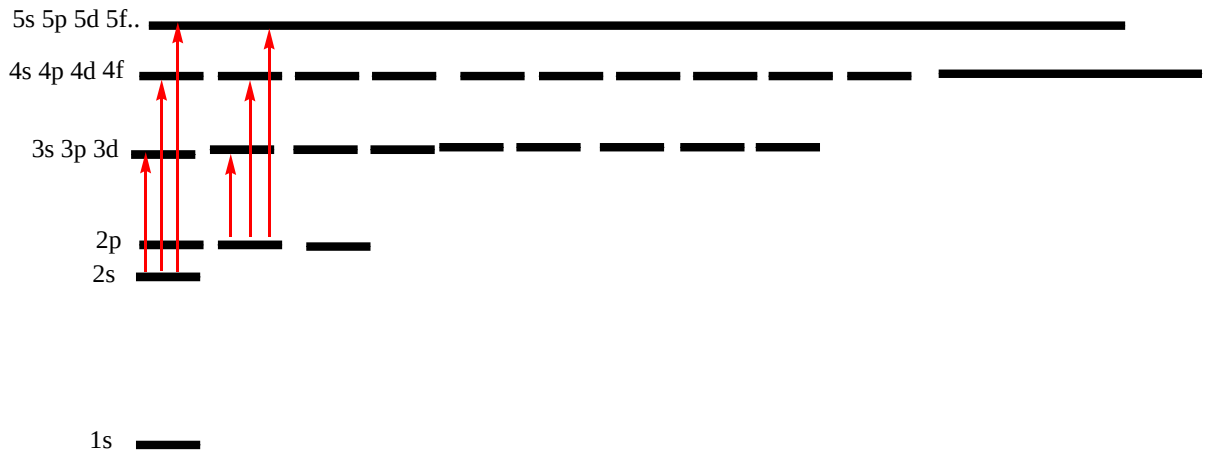
λ_1 = 36c/5R = 657 nm; (n=3; 3s, 3p, 3d) → (n=2; 2s, 2p)

λ_1 = 16c/3R = 486 nm; (n=4; 4s, 4p, 4d, 4f) → (n=2; 2s, 2p)

λ_1 = 100c/21R = 434 nm; (n=5; 5s, 5p, 5d, 5f) → (n=2; 2s, 2p)

(b) (4 pts) With two electrons in helium, subshell orbitals do not have the same energy level from n=2. Doubling of the lines means only the orbitals with n=2 quantum number have significantly different energy levels and thus the Balmer series has energy transfers from 2s and 2p energy levels.

(c) (3 pts)



4. (8 pts in total)

(a) (3 pts) Predicted electronic configuration of Ir (Z = 77) is $[Xe]4f^{14}5d^{7}6s^{2}$. Actual electronic configuration is $[Xe]4f^{14}5d^{9}$

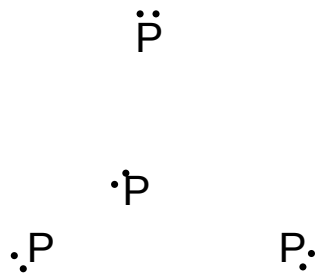
(b) (3 pts) Sc (Z = 21) is $[Ar]3d^{1}4s^{2}$ (paramagnetic)

Sc^{+} is $[Ar]3d^{1}4s^{1}$ (paramagnetic)

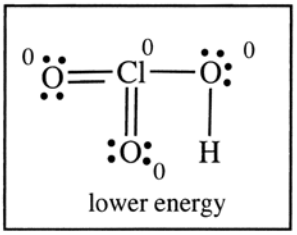
(c) (2 pts) Carbon (C)

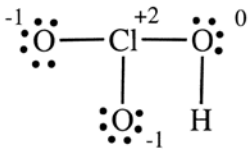
5. (9 pts in total)

(a) (3 pts) tetrahedral



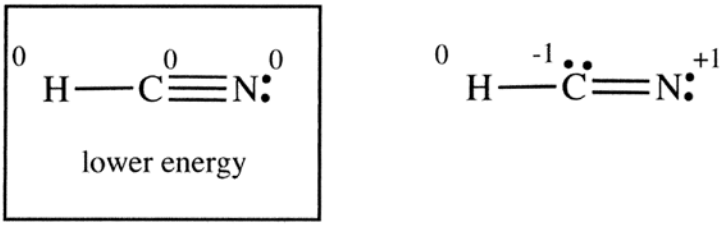
(b) (2 pts)





(c) (2 pts)

(d) (2 pts)



6. (10 pts in total)

(a-c) (each 2 pts) × 3

(a) The bond in HCl would be more ionic. The electronegativity difference is greater between H and Cl then between H and I, making the H—Cl bond more ionic.

(b) The bonds in CF_4 would be more ionic. The electronegativity difference is greater between C and F than between C and H, making the C—F bonds more ionic.

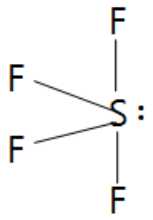
(c) C and S have nearly identical electronegativities, so the C—S bonds would be expected to be almost completely covalent, whereas the C—O bonds would be more ionic.

(d) (4 pts)

$O^{2-} < N^{3-} < Cl^- < Br^-$; the polarizability increases as the ion gets larger and less electronegative. The ionic radii for these species are 140 pm, 171 pm, 181 pm, 196 pm, respectively.

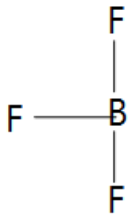
7. (10 pts in total)

(a-e) (each 1 pt) × 5

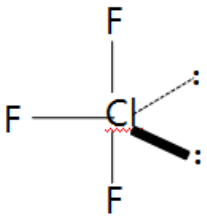
a) 

5 electron pairs about sulfur should have a trigonal bipyramidal arrangement

lone pairs occupy equatorial position

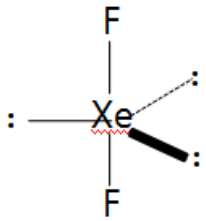
b) 

3 electron pairs about Boron have a Trigonal planar arrangement

c) 

5 electron pairs about chlorine have a trigonal bipyramidal arrangement

2 lone pairs occupy equatorial position

d) 

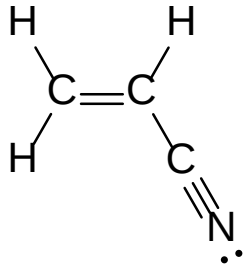
5 electron pairs about Xe have a trigonal bipyramidal arrangement

3 lone pairs occupy equatorial position

e) 

Linear arrangement

(f) (5 pts)



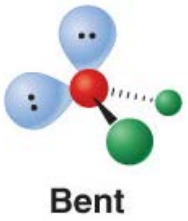
The first two carbons (CH_2 and CH) are sp^2 hybridized with H-C-H and C-C-H angles of 120°. The third carbon (bonded to N) is sp hybridized with a C-C-N angle of 180°.

8. (11 pts in total)

(a) (2 pts) H, $1s^1$

O, $1s^2 2s^2 2p^4$

(b) (2 pts)



bent or angular

(c) (4 pts)

- Four sp^3 hybrid orbitals
- Two of sp^3 hybrid orbitals occupied by two lone pair electrons
- Two of sp^3 hybrid orbitals with an unpaired electron forming O-H σ bonds

(d) (3 pts) six MOs from two hydrogen 1s orbitals and one 2s, three 2p oxygen orbitals

9. (11 pts in total)

(a) (5 pts)

(b-d) (each 2 pt) × 3

(a) (1) $\left(\sigma_{2s}\right)^2\left(\sigma_{2s}^*\right)^2\left(\sigma_{2p}\right)^2\left(\pi_{2p_x}\right)^2\left(\pi_{2p_y}\right)^2\left(\pi_{2p_x}^*\right)^2\left(\pi_{2p_y}^*\right)^2\left(\sigma_{2p}^*\right)^1$

(2) $\left(\sigma_{2s}\right)^2\left(\sigma_{2s}^*\right)^2\left(\sigma_{2p}\right)^2\left(\pi_{2p_x}\right)^2\left(\pi_{2p_y}\right)^2\left(\pi_{2p_x}^*\right)^2\left(\pi_{2p_y}^*\right)^1$

(3) $\left(\sigma_{2s}\right)^2\left(\sigma_{2s}^*\right)^2\left(\sigma_{2p}\right)^2\left(\pi_{2p_x}\right)^2\left(\pi_{2p_y}\right)^2\left(\pi_{2p_x}^*\right)^2\left(\pi_{2p_y}^*\right)^2\left(\sigma_{2p}^*\right)^2$

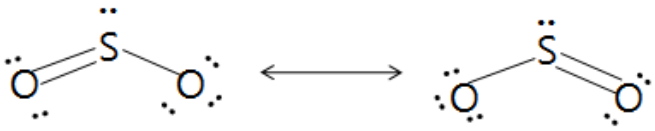
(b) (1) 0.5; (2) 1.5; (3) 0

(c) (1) and (2) are paramagnetic, with one unpaired electron each

(d) σ for (1) and (3), π for (2).

10. (15 pts in total)

(a) (3 pts)



(b) (5 pts)

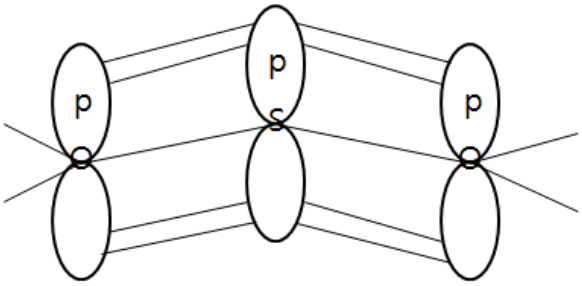
Each atom uses sp^2 hybrid orbital (planar 120^O network of S-O sigma bond).

The overlap of a hybrid orbital from sulfur with one from oxygen gives an S-O σ bond.

Four of the 18 electrons go into the 2 S-O bonds, while 10 go into the 5 lone pairs.

Four electrons and three unhybridized p orbital remain.

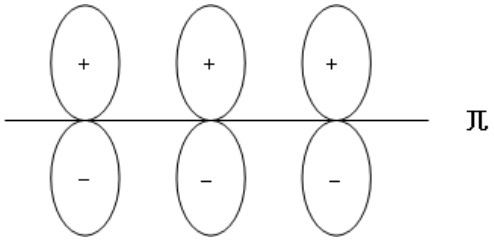
Perpendicular to the plane, these three p orbitals then combine to make a delocalized π orbitals for the last 4 electrons.



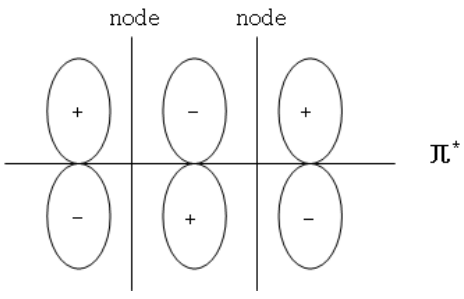
(c) (5 pts)

Three atomic p orbitals mix themselves into 3 π molecular orbitals.

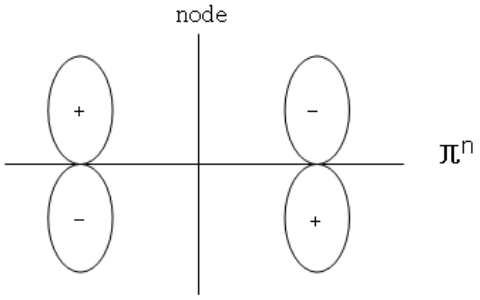
They mix constructively to produce π bonding combination with no nodes.



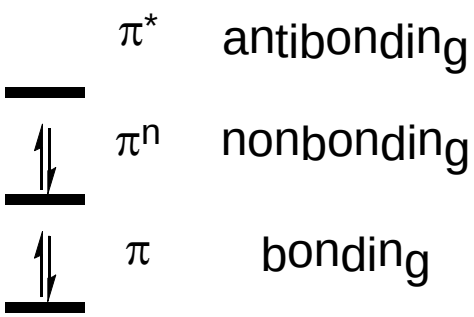
They mix destructively to produce π antibonding combination with two nodes



And they mix indifferently to produce a π nonbonding combination with one node.



4 π electrons therefore manage to lower the energy of the molecule.



(d) (2 pts)

π^n is HOMO (Highest Occupied Molecular Orbital).

2013 SPRING Semester Final Examination
For General Chemistry I

Date: June 19 (Wed), Time Limit: 7:00 ~ 9:00 p.m.

Write down your information neatly in the space provided below; print your Student ID in the upper right corner of every page.

Professor Name	Class	Student I.D. Number	Name

Problem	points	Problem	points	TOTAL pts
1	/18	**6**	/7	**/100**
2	/6	**7**	/10	
3	/8	**8**	/6	
4	/11	**9**	/10	
5	/8	**10**	/16	

** This paper consists of 12 sheets with 10 problems (page 10 & 11: constants & periodic table, page 12: claim form). Please check all page numbers before taking the exam. Write down your work and answers in the Answer sheet. Please write down the unit of your answer when applicable. You will get 30% deduction for a missing unit.

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

1. Period, Location and Procedure

1) Return and Claim Period: ***June 22 (Saturday, 11:00 ~ 13:00, 2 hours)***

2) ***Location: Creative Learning Bldg.(E11)***

Class	*Room*	*Class*	*Room*
A	**205**	**E**	**209**
B	**206**	**F**	**210**
C	**207**	**G**	**211**
D	**208**		

3) Claim Procedure:

Rule 1: Students cannot bring their own writing tools into the room. (Use a pen only provided by TA)

Rule 2: With or without claim, you must submit the paper back to TA. (Do not go out of the room with it)

(During the period, you can check the marked exam paper from your TA and should hand in the paper with a FORM for claims if you have any claims on it.)

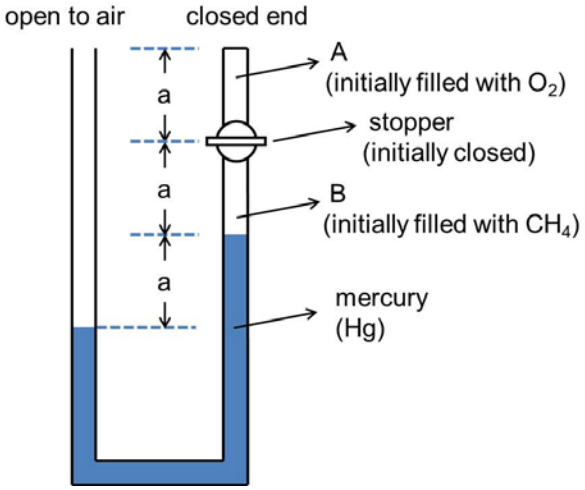
To get more information, visit the website at www.gencheminkaist.pe.kr.

2. Final Confirmation

1) Period: ***June 25 (Tuesday, 24 hours)***

2) Procedure: During this period, you can check the final score of the examination *on the website* again.

1. (18 points) Consider the following open-tube manometer filled with mercury. The temperature is maintained constant all the time. The left end is open to the atmosphere and the right end is closed. The atmospheric pressure is 760 Torr. The part A is initially filled with 0.2 mol O_2 gas and the part B is filled with 0.1 mol CH_4 gas. The parts A and B are initially separated by a stopcock. Initially the value of a is 200 mm. In other words, the right side of mercury is higher than the left side by 200 mm, and the initial volume of A is the same as that of B. Assume that the volume occupied by the stopcock is zero.



(a) What is the initial pressure of CH_4 gas? What is the initial pressure of O_2 gas?

(Answer)

(b) The stopper is rotated and the parts A and B are connected so that CH_4 and O_2 gases are mixed. Then the right side of mercury level would go up or down? Explain your answer. (Hint: Consider the pressure of A+B when the volumes of A and B momentarily do not change)

(Answer)

(c) Eventually what would be the new pressure of this mixed gas? (Hint: It would help you if you first know which side (left or right) would be eventually higher. For this purpose, consider the pressure of A+B by assuming both sides would have equal height.)

(Answer)

(d) The gas mixture is considered to be our system of interest. In this mixing process, what are the internal energy change (ΔU) and the entropy change (ΔS) of the system?

(Answer)

(e) Then a spark was given in the mixture of CH_4 and O_2 gas so that CH_4 undergoes a combustion reaction. Write down the chemical equation of the combustion reaction of CH_4 gas.

(Answer)

(f) If the combustion reaction goes until no more CH_4 is left, the right side of mercury level would go up or down? Explain your answer. (Hint: Consider the pressure of the gas mixture when the volumes of the gas mixture momentarily does not change)

(Answer)

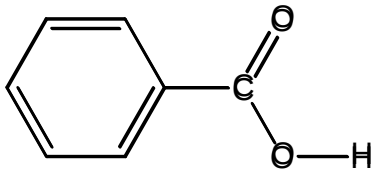
2. (6 points) A 1.00-L flask contains nitrogen gas at a temperature of 15 °C and a pressure of 0.50 bar. 0.10 mol $O_2(g)$ is added to the flask and allowed to mix. Then a stopcock is opened to allow 0.020 mol of molecules to escape. What is the partial pressure of oxygen in the final mixture?

(Answer)

3. (8 points) (a) N_2H_4 is used as a reducing agent and in the manufacture of rocket fuels. How do you expect its boiling point to compare with that of C_2H_2?

(Answer)

(b) Benzoic acid is able to form dimers (dimeric molecules) in the gas phase and in nonpolar solvents, such as tetrachloromethane.



Sketch one unit of benzoic acid dimer, showing clearly and naming the major intermolecular force responsible for dimerization. Would such dimers be present in ethanol?

(Answer)

4. (11 points) A sample consists of 8.00 kg of gaseous nitrogen and fills a 100 L flask at 300 ^{o}C.
The molar mass of N_2 gas is 28 g mol^{-1}, and R = 0.08206 L atm mol^{-1} K^{-1}.
The van der Waals constants of N_2 gas, *a* and *b*, are *a* = 1.390 atm L^2 mol^{-2}, *b* = 0.03913 L mol^{-1}.

(a) What is the pressure of the gas using the van der Waals equation?

(Answer)

(b) What is the compressibility factor (Z = PV/nRT) using the van der Waals equation?

(Answer)

(c) Obtain Boyle temperature (T_b) of the gas using the van der Waals equation. Note that Z = 1 at T_b.

(Answer)

5. (8 points) What fraction of the total space in a body-centered cubic unit cell is unoccupied? Assume that the central atom touches each of the eight corner atoms of the cube.

(Answer)

6. (7 points) Calculate the work for each of the following processes beginning with ideal gas sample in a piston assembly with T = 305 K, P = 1.79 atm, and V = 4.29 L;

(a) irreversible expansion against a constant external pressure of 1.00 atm to a final volume of 6.52 L;

(Answer)

(b) isothermal, reversible expansion to a final volume of 6.52 L.

(Answer)

7. (10 points)

(a) The enthalpy of formation of trinitrotoluene (TNT) is -67 kJ mol^{-1}, and the density of TNT is 1.65 g cm^{-3}. In principle, it could be used as a rocket fuel, with the gases resulting from its decomposition streaming out of the rocket to give the required thrust. In practice, of course, it would be extremely dangerous as a fuel because it is sensitive to shock. Explore its potential as a rocket fuel by calculating its enthalpy density (enthalpy released per liter) for the reaction:

$4\ C_7H_5N_3O_6(s) + 21\ O_2(g) \rightarrow 28\ CO_2(g) + 10\ H_2O(l) + 6\ N_2(g)$

(Standard enthalpies of formation (kJ mol^{-1}): $CO_2(g)$ –393.51; $H_2O(l)$ –241.82)

(Answer)

(b) Benzene (C_6H_6) is more stable than is predicted by its Kekule structure. Estimate this difference of molar energy if the standard enthalpy of formation of benzene liquid is +49.0 kJ mol^{-1} and the mean standard bond enthalpies (kJ mol^{-1}) of a Kekule structure are +412 (C-H); +348 (C-C) and +612 (C=C). The standard bond enthalpy of $H_2(g)$ is +436 kJ mol^{-1} and of C(s, graphite) is +717 kJ mol^{-1}.

(Answer)

8. (6 points) If SO_2F_2 adopts a disordered arrangement in its crystal form, what would its residual molar entropy be?

(Answer)

9. (10 points) Calculate the standard entropy of vaporization of water at 85 ^{o}C, given that its standard entropy of vaporization at 100 ^{o}C is 109.0 J K^{-1} mol^{-1} and the molar heat capacities at constant pressure of liquid water and water vapor are 75.3 J K^{-1} mol^{-1} and 33.6 J K^{-1} mol^{-1}, respectively, in this range.

(Answer)

10. (16 points)

For the two processes below (a and b), calculate the entropy change associated with the expansion of 5.00 mol of an ideal monatomic gas, at 298.0 K, from a pressure of 10.0 atm to 1.00 atm.

(a) Reversibly, at a constant temperature of 298.0 K. (4 points)

(Answer)

(b) Reversibly and adiabatically, so that the system temperature drops to 118.6 K, followed by reversible heating of the gas at constant pressure back to 298.0 K.

(Answer)

The standard enthalpy (ΔH^o) and entropy (ΔS^o) of vaporization of chloroform ($CHCl_3$) are +31.4 kJ mol^{-1} and +93.8 J mol^{-1} K^{-1}, respectively.

(c) Calculate the standard Gibbs free energy change of vaporization (ΔG^o) of 1 mol of chloroform at 0 ^oC and comment on whether the process is favorable at this temperature.

(Answer)

(d) Calculate the boiling point (in ^oC) of chloroform.

(Answer)

FUNDAMENTAL CONSTANTS

Name	Symbol	Value
Atomic mass constant	m_u	$1.660\,54 \times 10^{-27}$ kg
Avogadro's constant	N_A	$6.022\,14 \times 10^{23}$ mol^{-1}
Boltzmann's constant	k	$1.380\,65 \times 10^{-23}$ J·K^{-1}
Fundamental charge	e	$1.602\,18 \times 10^{-19}$ C
Faraday's constant	$F = N_A e$	$9.648\,53 \times 10^{4}$ C·mol^{-1}
Gas constant	$R = N_A k$	$8.314\,47$ J·K^{-1}·mol^{-1}
		$8.314\,47$ L·kPa·K^{-1}·mol^{-1}
		$8.205\,74 \times 10^{-2}$ L·atm·K^{-1}·mol^{-1}
		$62.36\,37$ L·Torr·K^{-1}·mol^{-1}
		$8.314\,47 \times 10^{-2}$ L·bar·K^{-1}·mol^{-1}
Mass of electron	m_e	$9.109\,38 \times 10^{-31}$ kg
Mass of neutron	m_n	$1.674\,93 \times 10^{-27}$ kg
Mass of proton	m_p	$1.672\,62 \times 10^{-27}$ kg
Planck's constant	h	$6.626\,08 \times 10^{-34}$ J·s
	$\hbar = h/2\pi$	$1.054\,57 \times 10^{-34}$ J·s
Rydberg constant	$\mathcal{R}$	$3.289\,84 \times 10^{15}$ Hz
Speed of light	c	$2.997\,92 \times 10^{8}$ m·s^{-1}
Standard acceleration of free fall	g	$9.806\,65$ m·s^{-2}
Vacuum permittivity	ε_0	$8.854\,19 \times 10^{-12}$ J^{-1}·C^2·m^{-1}

RELATIONS BETWEEN UNITS*

Property	Common unit	SI unit
Mass	2.205 lb (lb = pound)	1.000 kg
	1.000 lb	453.6 g
	1.000 oz (oz = ounce)	28.35 g
	1.000 ton (= 2000 lb)	907.2 kg
	1 t (t = tonne, metric ton)	**10^3 kg**
Length	1.094 yd (yd = yard)	1.000 m
	0.3937 in. (in. = inch)	1.000 cm
	0.6214 mi (mi = mile)	1.000 km
	1 in.	**2.54 cm**
	1 ft (ft = foot)	**30.48 cm**
	1.000 yd	0.9144 m
	1 Å (Å = ångström)	**10^{-10} m**
Volume	**1 L (L = liter)**	**10^3 cm^3, 1 dm^3**
	1.000 gal (gal = gallon)†	3.785 dm^3 (3.785 L)
	1.00 ft^3 (ft^3 = cubic foot)	2.83×10^{-2} m^3 (28.3 L)
	1.00 qt (qt = quart)†	9.46×10^{2} cm^3 (0.946 L)
Time	**1 min (min = minute)**	**60 s**
	1 h (h = hour)	**3600 s**
	1 day	**86 400 s**
Pressure	**1 atm (atm = atmosphere)**	**$1.013\,25 \times 10^5$ Pa**
	1.000 Torr or 1.000 mmHg	133.3 Pa
	1.000 psi (psi = pounds per square inch)	6.895 kPa
	1 bar	**10^5 Pa**
Energy	**1 cal**	**4.184 J**
	1 eV	1.60218×10^{-19} J; 96.485 kJ·mol^{-1}
	1 C·V	**1 J**
	1 kWh (kWh = kilowatt hour)	**3.600×10^3 kJ**
	1 L·atm	**101.325 J**

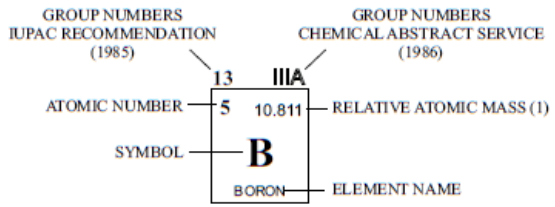
Temperature conversions	(Fahrenheit temperature)/°F = $\frac{9}{5}$ × (Celsius temperature)/°C + 32
	(Celsius temperature)/°C = $\frac{5}{9}$ + {(Fahrenheit temperature)/°F − 32}
	(Kelvin temperature)/K = (Celsius temperature)/°C + 273.15

*Entries in boldface type are exact.

†The European and Canadian Imperial quart and gallon are 1.201 times as large.

PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/



PERIOD / GROUP	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 **H** HYDROGEN																	2 4.0026 **He** HELIUM
2	3 6.941 **Li** LITHIUM	4 9.0122 **Be** BERYLLIUM											5 10.811 **B** BORON	6 12.011 **C** CARBON	7 14.007 **N** NITROGEN	8 15.999 **O** OXYGEN	9 18.998 **F** FLUORINE	10 20.180 **Ne** NEON
3	11 22.990 **Na** SODIUM	12 24.305 **Mg** MAGNESIUM											13 26.982 **Al** ALUMINIUM	14 28.086 **Si** SILICON	15 30.974 **P** PHOSPHORUS	16 32.065 **S** SULPHUR	17 35.453 **Cl** CHLORINE	18 39.948 **Ar** ARGON
4	19 39.098 **K** POTASSIUM	20 40.078 **Ca** CALCIUM	21 44.956 **Sc** SCANDIUM	22 47.867 **Ti** TITANIUM	23 50.942 **V** VANADIUM	24 51.996 **Cr** CHROMIUM	25 54.938 **Mn** MANGANESE	26 55.845 **Fe** IRON	27 58.933 **Co** COBALT	28 58.693 **Ni** NICKEL	29 63.546 **Cu** COPPER	30 65.39 **Zn** ZINC	31 69.723 **Ga** GALLIUM	32 72.64 **Ge** GERMANIUM	33 74.922 **As** ARSENIC	34 78.96 **Se** SELENIUM	35 79.904 **Br** BROMINE	36 83.80 **Kr** KRYPTON
5	37 85.468 **Rb** RUBIDIUM	38 87.62 **Sr** STRONTIUM	39 88.906 **Y** YTTRIUM	40 91.224 **Zr** ZIRCONIUM	41 92.906 **Nb** NIOBIUM	42 95.94 **Mo** MOLYBDENUM	43 (98) **Tc** TECHNETIUM	44 101.07 **Ru** RUTHENIUM	45 102.91 **Rh** RHODIUM	46 106.42 **Pd** PALLADIUM	47 107.87 **Ag** SILVER	48 112.41 **Cd** CADMIUM	49 114.82 **In** INDIUM	50 118.71 **Sn** TIN	51 121.76 **Sb** ANTIMONY	52 127.60 **Te** TELLURIUM	53 126.90 **I** IODINE	54 131.29 **Xe** XENON
6	55 132.91 **Cs** CAESIUM	56 137.33 **Ba** BARIUM	57-71 **La-Lu** Lanthanide	72 178.49 **Hf** HAFNIUM	73 180.95 **Ta** TANTALUM	74 183.84 **W** TUNGSTEN	75 186.21 **Re** RHENIUM	76 190.23 **Os** OSMIUM	77 192.22 **Ir** IRIDIUM	78 195.08 **Pt** PLATINUM	79 196.97 **Au** GOLD	80 200.59 **Hg** MERCURY	81 204.38 **Tl** THALLIUM	82 207.2 **Pb** LEAD	83 208.98 **Bi** BISMUTH	84 (209) **Po** POLONIUM	85 (210) **At** ASTATINE	86 (222) **Rn** RADON
7	87 (223) **Fr** FRANCIUM	88 (226) **Ra** RADIUM	89-103 **Ac-Lr** Actinide	104 (261) **Rf** RUTHERFORDIUM	105 (262) **Db** DUBNIUM	106 (266) **Sg** SEABORGIUM	107 (264) **Bh** BOHRIUM	108 (277) **Hs** HASSIUM	109 (268) **Mt** MEITNERIUM	110 (281) **Uun** UNUNNILIUM	111 (272) **Uuu** UNUNUNIUM	112 (285) **Uub** UNUNBIUM		114 (289) **Uuq** UNUNQUADIUM				

LANTHANIDE

6	57 138.91 **La** LANTHANUM	58 140.12 **Ce** CERIUM	59 140.91 **Pr** PRASEODYMIUM	60 144.24 **Nd** NEODYMIUM	61 (145) **Pm** PROMETHIUM	62 150.36 **Sm** SAMARIUM	63 151.96 **Eu** EUROPIUM	64 157.25 **Gd** GADOLINIUM	65 158.93 **Tb** TERBIUM	66 162.50 **Dy** DYSPROSIUM	67 164.93 **Ho** HOLMIUM	68 167.26 **Er** ERBIUM	69 168.93 **Tm** THULIUM	70 173.04 **Yb** YTTERBIUM	71 174.97 **Lu** LUTETIUM

ACTINIDE

7	89 (227) **Ac** ACTINIUM	90 232.04 **Th** THORIUM	91 231.04 **Pa** PROTACTINIUM	92 238.03 **U** URANIUM	93 (237) **Np** NEPTUNIUM	94 (244) **Pu** PLUTONIUM	95 (243) **Am** AMERICIUM	96 (247) **Cm** CURIUM	97 (247) **Bk** BERKELIUM	98 (251) **Cf** CALIFORNIUM	99 (252) **Es** EINSTEINIUM	100 (257) **Fm** FERMIUM	101 (258) **Md** MENDELEVIUM	102 (259) **No** NOBELIUM	103 (262) **Lr** LAWRENCIUM

(1) Pure Appl. Chem., **73**, No. 4, 667-683 (2001)

Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@netlinx.com)

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Claim Form for General Chemistry Examination Page (/)

Class:_____, Professor Name:_____, Student I.D.:_____, Name:_____

If you have any claims on the marked paper, please write down them on this form and ***submit this with your paper in the assigned place.*** (And this form should be attached ***on the top of the marked paper with a stapler.***) Please, ***copy this sheet if you need more before use.***

By Student		By TA	
		Accepted? Yes(√) or No(√)	
Question #	Claims	Yes: ☐	No: ☐
		Pts (+/−)	Reasons

<The Answers>

Problem	points	Problem	points	TOTAL pts
1	2+3+4+4+2+3 /18	**6**	3+4 /7	**/100**
2	6 /6	**7**	5+5 /10	
3	2+6/8	**8**	6 /6	
4	3+4+4 /11	**9**	4+2+4+2/10	
5	8 /8	**10**	4+4+4+4/16	

Missing units in the answer: -1 pt

"-1 pt" means "minus 1 point"

1. (total 18 points)

(a) **(2 pts)** The pressure of CH_4 gas = 760 Torr - 200 Torr = **560 Torr**.

The temperature and volume are the same for A and B. On the other hand, A has two times more molecules than B. Therefore, the pressure should be also two times larger.

The pressure of O_2 gas = 2 × 560 Torr = **1120 Torr**.

각 **1 pt**

(b) **(3 pts)** It would be easier if we consider the situation where the volume remains unchanged.

In this case, if we set V = initial volume of B, then the final volume of A+B is 2V.

The initial pressure of A = P_A = 0.2RT/V.

The initial pressure of B = P_B = 0.1RT/V.

The final pressure of A+B = P = 0.3RT/(2V) = (P_A + P_B)/2 = (560 Torr + 1220 Torr)/2 = 840 Torr.

Since this is higher than the atmospheric pressure (760 Torr), **the right side of mercury should go down.**

설명 없이 **down** 만 썼을 경우 **1 pt**

(c) **(4 pts)** If both sides have the same height, that means that the right side moved down by a/2 (=100 mm) and the left side moved up by 100 mm. Then the new volume of A+B = 2.5V.

Therefore P × 2.5V = 840 Torr × 2V. P = 672 Torr. This is now lower than the atmospheric pressure (760 Torr). This means that the right side would not go down this much. In other words, the right side would be still higher.

P_f = final pressure of A+B. V_f = final volume of A+B. If the right side moves down by b mm with respect to the initial position (at which the right side is higher by 200 mm), then the right side would be higher than the left side by 200 mm - 2b.

In addition $V_f = 2V \times$ **(400 + b)/400**.

P_fV_f = 840 Torr × 2V.

$P_f \times 2V \times$ (**400 + b**)/**400** = 840 Torr × 2V (eq 1)

In addition, the left side and right side pressure should balance. Therefore

760 Torr = P_f + 200 - 2b (eq 2)

Solving eqs 1 and 2 gives b = 74.26 mm, **P_f = 708.5 Torr**.

논리적이지만 답만 틀릴 경우 -1 pt

(d) **(4 pts)** Since the temperature is maintained constant, ΔT = 0. Thus **ΔU = 0.**

For the 0.2 mol O_2 gas, $\Delta S = nR \ln(V_2/V_1) = 0.2R \ln((200+200+74.26)/(200)) = 0.17R$

For the 0.1 CH_4 gas, $\Delta S = nR \ln(V_2/V_1) = 0.1R \ln((200+200+74.26)/(200)) = 0.086R$

Thus **ΔS = 0.17R + 0.086R = 0.259R = 2.15 J/K**

ΔU 1 pt; ΔS 2 pts

(e) **(2 pts)** A combustion reaction is the reaction with O2 gas to give CO_2(g) and H_2O(l).

Therefore, **CH_4(g) + 2 O_2(g) → CO_2(g) + 2 H_2O(l).**

Stoichiometry 틀릴 경우 -1 pt

(f) **(3 pts)** Due to the reaction, 3 gas molecules are reduced to 1 gas molecule. So if the volume does not change, the pressure would go down by three times and the new pressure would be momentarily 615/3 Torr = **205 Torr**. **The right side of mercury level would go up.**

설명이 없이 up 만 썼을 경우 1 pt

2. **(total 6 points)**

$$n_{\text{total}} = n_{N_2} + n_{O_2}\,;\, n_{N_2} = \frac{PV}{RT} = \frac{(0.50\text{ bar}) \times \left(\frac{1\text{ atm}}{1.01325\text{ bar}}\right) \times (1.00\text{ L})}{(0.08206\text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}) \times (288\text{ K})}$$

$$= 0.021\text{ mol}$$

$$n_{\text{total}} = 0.021 + 0.10 = 0.12\text{ mol};\; x_{\text{nitrogen}} = \left(\frac{0.021}{0.12}\right) = 0.18;\; x_{\text{oxygen}} = 0.82$$

If 0.020 mol were released, then

$$n_{\text{left}} = 0.10\text{ mol and } n_{\text{oxygen}} = (0.82) \times (0.10\text{ mol}) = 0.082\text{ mol}$$

$$P_{O_2} = \frac{nRT}{V} = \frac{(0.082\text{mol}) \times (0.08206\text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}) \times (288\text{K})}{1.00\text{L}}$$

$$= 1.9\text{ atom}$$

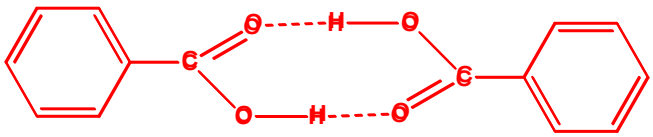
전개가 다 맞으나 계산만 틀린 경우 **-1 pt**

Mole fraction 까지만 맞은 경우 **2 pts**

3. (total 8 points)

(a) **(2 pts)** The boiling point of N_2H_4 would be higher than that of C_2H_4 because N-H…N hydrogen bonds are present in N_2H_4 but not in C_2H_4.

(b) **(6 pts)**



---- Hydrogen bonding

No, this dimer would not form much in ethanol solution because of the strong competition from ethanol for hydrogen bonding

그림 4 pts, 한 hydrogen bonding 만 그릴 경우 2 pts

Ethanol 조건에 대한 description 2 pts

4. (11 points)

a) $P = \frac{nRT}{V-nb} - a\frac{n^2}{V^2}$

$= \frac{(286)(0.082)(573)}{100-(286)(0.03913)} - (1.390)\left(\frac{286}{100}\right)$

$= 139.94 atm \simeq 140 atm$ **(3 pts)**

b) $Z \cong 1 + (b - \frac{a}{RT})(\frac{n}{V}) + ...$

$= 1 + (0.03913 - \frac{1.390}{0.082 \times 573})(\frac{286}{100}$

$= 1.0273$ **(4 pts)**

c) $T_B = \frac{a}{Rb} = \frac{1.390}{0.08206 \times 0.03913} = 432.88$ **(4 pts)**

식은 맞되 계산만 틀릴 경우 **-1 pt**

5. **(total 8 points)**

# of atoms in unit cube = (1/8 atom/corner X 8 corners) + 1atom (in center) = 2 atoms

Volume of 2 atoms = 2 X 4/3 $\pi(1)^3$ = 8.38

The radius of atoms is taken to be 1.

Volume of the cube = $(4/\sqrt{3})^3$ = 12.32

Volume of space = Volume of cube - Volume of spheres = 12.32 - 8.38 = 3.94

percentage of cube taken by space = 3.94 / 12.32 x 100 = **32%**

답만 맞을 경우 5 pts, 전개과정은 맞되 답만 틀린 경우 -1 pt

6. (total 7 points)

(a) The irreversible work of expansion against a constant opposing pressure is given by

$$w = -P_{ex}\Delta V$$

$$w = -(1.00\ \text{atm})(6.52\ \text{L} - 4.29\ \text{L})$$

$$= -2.23\ \text{L}\cdot\text{atm}$$

$$= -2.23\ \text{L}\cdot\text{atm} \times 101.325\ \text{J}\cdot\text{L}^{-1}\cdot\text{atm}^{-1} = -226\ \text{J}$$

(3 pts)

부호 틀린 경우 **- 1 pt**

(b) An isothermal expansion will be given by

$$w = -nRT\frac{V_2}{V_1}$$

n is calculated from the ideal gas law:

$$n = \frac{PV}{RT} = \frac{(1.79\ \text{atm})(4.29\ \text{L})}{(0.082\ 06\ \text{L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(305\ \text{K})} = 0.307\ \text{mol}$$

$$w = -(0.307\ \text{mol})(8.314\ \text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(305\ \text{K})\ln\frac{6.52}{4.29}$$

$$= -326\ \text{J}$$

(4 pts)

부호 틀린 경우 **- 1 pt**

7. (total 10 points)

(a) **(5 pts)**

The enthalpy of reaction for the reaction

$4C_7H_5N_3O_6(s) + 21\ O_2(g) \rightarrow 28\ CO_2(g) + 10\ H_2(g) + 6\ N_2(g)$

May be found using enthapies of formation:

28 (-393.51 kJ/mol) +10(-241.82 kJ/mol) – 4(+67 kJ/mol) = **-13704 kJ/mol**

This is the energy released per mole of reaction as written. One fourth of this amount of energy or **3426 kJ/mol** will be released per mole of TNT consumed. The energy density in kJ per L may be found by dividing this amount of energy with the mass of one mole of TNT and then by multiplying with the density of TNT:

{(3426 kJ/mol)/ 227.14 g/mol} (1.65 g/cm^3) (10^3 cm^3 / 1L) = **+ 24.9 X 10^3 kJ/L**

3426 kJ/mol 까지만 쓴 경우 **2 pts**

(b) **(5 pts)**

$6C(s, gr) + 3H_2(g) \longrightarrow C_6H_6(l);\ \Delta H^\theta_f = +49.0\ kJ\ mol^{-1}$

Bonds broken (in kJ)

6 x +717 + 3 x +436 = +5610 kJ

Bonds made (in kJ), assuming 3 isolated C=C and 3 isolated C-C of Kekule structure

3 x −612 + 3 x −348 + 6 x −412 = − 5352 kJ

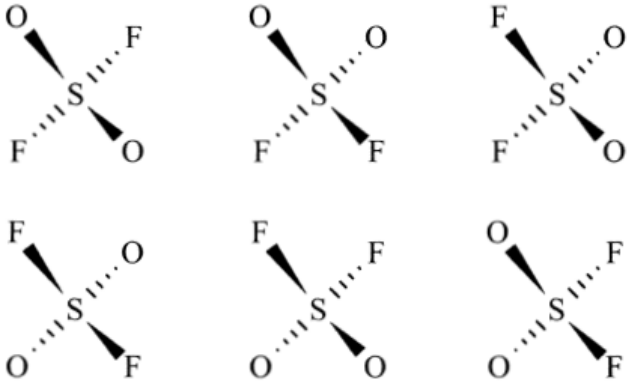
This gives $\Delta H^\theta_f = +258\ kJ\ mol^{-1}$

The real benzene molecule is thus more stable than Kekule structure by 209 kJ mol^{-1}

부호 **-1 pt**

8. **(total 6 points)**

There are six orientations of an SO_2F_2 molecule as shown below:



$$S = k\ \ln 6^{6.02\times10^{23}} = (1.38\times10^{-23}\ \mathrm{J\cdot K^{-1}})\ln 6^{6.02\times10^{23}}$$

$$S = 14.9\ \mathrm{J\cdot K^{-1}}$$

Orientation 개수가 틀려 답이 틀린 경우 -4 pts

9. **(total 10 points)**

The entropy of vaporization of water at 85 °C may be carried out through a series of three reversible steps. Namely, reversibly heating the reactants to 100 °C, carrying out the phase change at this temperature, and finally cooling the products back to 85 °C. The sum of the ΔS's for these three steps will be equivalent to vaporizing water at 85 °C in one irreversible step.

Step 1, heating the reactants to 100 °C:

$$\Delta S_1 = C_{P,m} \ln\left(\frac{T_2}{T_1}\right) = \left(75.3\ \mathrm{J\cdot K^{-1}\cdot mol^{-1}}\right)\ln\left(\frac{373\ \mathrm{K}}{358\ \mathrm{K}}\right) = 3.09\ \mathrm{J\cdot K^{-1}\cdot mol^{-1}}$$

Step 2, the entropy of vaporization of H_2O at 100 °C is $109.0\ \mathrm{J\cdot K^{-1}\cdot mol^{-1}}$

Step 3, cooling the products to 85 °C:

$$\Delta S_3 = C_{P,m} \ln\left(\frac{T_2}{T_1}\right) = \left(33.6\ \mathrm{J\cdot K^{-1}\cdot mol^{-1}}\right)\ln\left(\frac{358\ \mathrm{K}}{373\ \mathrm{K}}\right) = -1.38\ \mathrm{J\cdot K^{-1}\cdot mol^{-1}}$$

Therefore, the molar entropy of vaporization is H_2O at 85 °C is:

$$\Delta S_{\mathrm{v,m}} = \Delta S_1 + \Delta S_2 + \Delta S_3 = 111\ \mathrm{J\cdot K^{-1}\cdot mol^{-1}}.$$

ΔS_1 3 pts; ΔS_2 2 pts; ΔS_3 3 pts; sum 2 pts

10. (total 16 points)

(a) **(4 pts)** At constant temperature, the entropy change is given by

$\Delta S = nR \ln(V_2/V_1) = nR \ln(P_1/P_2) = (5.00 \text{ mol})(8.315 \text{ J K}^{-1} \text{ mol}^{-1}) \ln 10$

$= \underline{\mathbf{+95.7 \text{ J K}^{-1}}}$

부호 **-1 pt**

(b) **(4 pts)** For the adiabatic part of this path, entropy change is 0. For the reversible heating at constant pressure from 118.6 K to 298.0 K, the entropy change is

$\Delta S = nC_p \ln(T_2/T_1) = (5.00 \text{ mol})(5/2 \times 8.315 \text{ J K}^{-1} \text{ mol}^{-1}) \ln(298.0 \text{ K} / 118.6 \text{ K})$

$= \underline{\mathbf{+95.7 \text{ J K}^{-1}}}$

부호 **-1 pt**

(c) **(4 pts)** $\Delta G^\theta = \Delta H^\theta - T\Delta S^\theta$

$= 31400 \text{ J/mol} - (233 \text{ K})(93.8 \text{ J/K mol})$

$= \underline{+5793 \text{ J mol}^{-1}}$

Because $\Delta G^\theta > 0$, vaporization of chloroform at 0 °C (273 K) is NOT spontaneous

부호 **-1 pt, no comments -1 pt**

(d) **(4 pts)** At the equilibrium between chloroform vapor and liquid (at the boiling point, T_b, of chloroform), $\Delta G = 0$

Hence $\Delta H^o = T_b \Delta S^o$ (assuming negligible variations of ΔH^o and ΔS^o with T

$$T_b = \frac{\Delta H^o}{\Delta S^o} = \frac{31400 \text{ J/mol}}{93.8 \text{ J/K mol}} = \underline{\mathbf{334.6 \text{ K or } 61.6\ ^oC}}$$