

2019 Spring Semester Midterm Examination For General Chemistry I

Date: April 17 (Wed), Time Limit: 19:00 ~ 21:00

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	/10	6	/10	/100
2	/10	7	/12	
3	/10	8	/6	
4	/10	9	/10	
5	/6	10	/16	

** This paper consists of 9 sheets with 10 problems (page 11 - 13: Equation, constants & periodic table, page 14: 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 22 (*Mon, 7: 00 ~ 8:00 p.m.*)
- 2) **Location: Room for quiz sessions**
- 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 the web.)

2. Final Confirmation

- 1) Period: April 25 (Thu) – April 26 (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. (total 10 pts)

Suppose an element (X) in the 2nd period. The following table shows a series of the ionization energy of X.

	IE ₁	IE ₂	IE ₃	IE ₄	IE ₅	IE ₆	IE ₇	IE ₈
X	17.42	34.97	62.71	87.14	114.24	157.16	185.18	953.89

Ionization energy is given as eV

(a) [3 pts] What is this element X?

(Answer)

Fluorine (F)

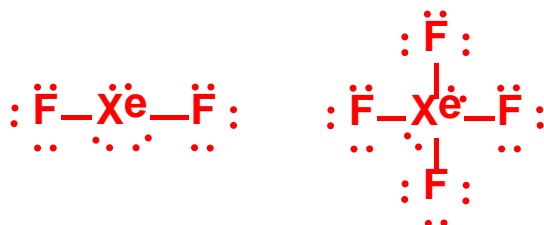
(b) [3 pts] IE₈ is significantly higher than IE₇. Explain why.

(Answer)

IE₈ is the required energy to get rid of one electron from F⁷⁺ which has the same electron configuration of He. Therefore, it requires additional much energy to remove an electron in the first shell.

(c) [4 pts] This element X can form XeX₂ and XeX₄. Draw the Lewis structure of each molecule, and predict their geometries using the VSEPR theory.

(Answer)



XeF₂ = linear structure, XeF₄ = square planar structure

2. (total 10 pts)

Light with a wavelength of 525 nm strikes the surface of cesium in a photocell. The work function of cesium is $3.43 \times 10^{-19} \text{ J}$.

(a) [3 pts] Calculate the maximum velocity of the photoelectrons.

(b) [4 pts] Compute the de Broglie wavelength for the photoelectron in (a).

(c) [3 pts] Determine the longest wavelength of light that is capable of ejecting electrons from the surface of cesium.

(Answer)

$$(a) E = hv = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34} \text{ Js})(3.00 \times 10^8 \text{ ms}^{-1})}{525 \times 10^{-9} \text{ m}} = 3.79 \times 10^{-19} \text{ J}$$

$$E_k = \frac{1}{2}mv^2 = E - E_0 = (3.79 - 3.43) \times 10^{-19} \text{ J} = 3.6 \times 10^{-20} \text{ J}$$

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 3.6 \times 10^{-20} \text{ kgm}^2 \text{ s}^{-2}}{9.11 \times 10^{-31} \text{ kg}}} = 2.81 \times 10^5 \text{ ms}^{-1}$$

$$(b) \lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34} \text{ Js}}{(9.11 \times 10^{-31} \text{ kg})(2.81 \times 10^5 \text{ ms}^{-1})} = 2.59 \times 10^{-9} \text{ m}$$

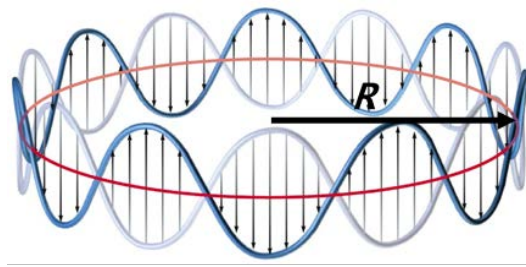
(c) The longest wavelength to promote the photoelectric effect for cesium occurs when the light energy matches the work function since

$$\Phi = 3.43 \times 10^{-19} \text{ J} = hv_0 = hc/\lambda_0 \quad E_{\text{max}} = \frac{1}{2} mv_e^2 = hv - \Phi$$

$$\lambda_0 = (6.626 \times 10^{-34} \text{ J s} \times 3.00 \times 10^8 \text{ m s}^{-1}) / 3.43 \times 10^{-19} \text{ J} = 5.80 \times 10^{-7} \text{ m or } 580 \text{ nm}.$$

3. (total 10 pts)

Let's consider that a particle with mass m is circulating around the origin with a radius of R , i.e., a particle in a loop. This particle can be described using a circular standing wave oscillating about the center with a radius of R .



Then, the wavelength λ and R can be related as $n\lambda = 2\pi R$, where $n = 1, 2, 3, \dots$, and the wavefunction can be expressed as $\psi(x) = A \sin \frac{2\pi x}{\lambda}$.

(a) [6 pts] Using the Schrödinger equation, calculate the quantized energy levels of this particle. Note that no potential is involved in the particle's motion.

(b) [4 pts] Using the relation between the momentum (p) and the kinetic energy, calculate the momentum of this particle as a function of the wavelength λ . Compare the result with the de Broglie's hypothesis between p and λ .

(Answer)

(a)

From the boundary condition, the wavefunction is written as

$$\psi(x) = A \sin \frac{2\pi x}{\lambda} = A \sin \frac{nx}{R}$$

The Schrödinger equation is rearranged as

$$\frac{d^2\psi(x)}{dx^2} = -\frac{8\pi^2mE}{h^2}\psi(x)$$

Then,

$$L.H.S. = \frac{d^2\psi(x)}{dx^2} = -\left(\frac{n}{R}\right)^2 A \sin \frac{nx}{R} = -\left(\frac{n}{R}\right)^2 \psi(x)$$

By comparing the L.H.S. and the R.H.S., we obtain

$$\frac{8\pi^2mE}{h^2} = \left(\frac{n}{R}\right)^2$$

$$E = \frac{1}{8m} \left(\frac{nh}{\pi R}\right)^2$$

(b)

$$p = \sqrt{2mE} = \frac{nh}{2\pi R} = \frac{h}{\lambda}$$

Thus, we obtain the same result with the de Broglie's hypothesis that is $\lambda = \frac{h}{p}$

4. (total 10 pts)

Photoelectron spectroscopy studies of silicon atoms excited by X-rays with wavelength of $9.890 \times 10^{-10} \text{ m}$ show four peaks in which the electrons have the following speeds:

$$2.097 \times 10^7 \text{ m s}^{-1}, 2.093 \times 10^7 \text{ m s}^{-1}, 2.014 \times 10^7 \text{ m s}^{-1}, 1.971 \times 10^7 \text{ m s}^{-1}$$

(a) [4 pts] Calculate the ionization energy of the electrons in each peak.

(b) [4 pts] Assign each peak to an orbital of the silicon atom.

(c) [2 pts] An electromagnetic wave with wavelength λ excited an electron from the 3s orbital to the 3p orbital.

Using the photoelectron spectroscopy data, calculate the value of λ .

(Answer)

a) The energy of the x-radiation used to irradiate the silicon atoms in this experiment is

$$\begin{aligned} E_{\text{x-rays}} = h\nu = \frac{hc}{\lambda} &= \frac{(6.62607 \times 10^{-34} \text{ J s})(2.99792 \times 10^8 \text{ m s}^{-1})}{9.890 \times 10^{-10} \text{ m}} = 2.0085 \times 10^{-16} \text{ J} \\ &= 2.0085 \times 10^{-16} \text{ J} \left(\frac{1 \text{ eV}}{1.6022 \times 10^{-19} \text{ J}} \right) = 1253.6 \text{ eV} \end{aligned}$$

Use the equation

$$IE = h\nu - \frac{1}{2} m_e v^2$$

as follows

$$IE_1 = 1253.6 \text{ eV} - \frac{(9.10938 \times 10^{-31} \text{ kg})(2.097 \times 10^7 \text{ m s}^{-1})^2}{2} \left(\frac{1 \text{ eV}}{1.6022 \times 10^{-19} \text{ J}} \right) = 3.5 \text{ eV}$$

$$IE_2 = 1253.6 \text{ eV} - \frac{(9.10938 \times 10^{-31} \text{ kg})(2.093 \times 10^7 \text{ m s}^{-1})^2}{2} \left(\frac{1 \text{ eV}}{1.6022 \times 10^{-19} \text{ J}} \right) = 8.3 \text{ eV}$$

$$IE_3 = 1253.6 \text{ eV} - \frac{(9.10938 \times 10^{-31} \text{ kg})(2.014 \times 10^7 \text{ m s}^{-1})^2}{2} \left(\frac{1 \text{ eV}}{1.6022 \times 10^{-19} \text{ J}} \right) = 100.5 \text{ eV}$$

$$IE_4 = 1253.6 \text{ eV} - \frac{(9.10938 \times 10^{-31} \text{ kg})(1.971 \times 10^7 \text{ m s}^{-1})^2}{2} \left(\frac{1 \text{ eV}}{1.6022 \times 10^{-19} \text{ J}} \right) = 149.2 \text{ eV}$$

+ 1pt for each correct ionization energy value

b) The ground-state electron configuration of silicon is $1s^2 2s^2 2p^6 3s^2 3p^2$. Peak 1 corresponds to removal of silicon's 3p electrons, which are its least tightly bound electrons. Peaks 2, 3, and 4 correspond to removal of Si's 3s, 2p, and 2s electrons respectively. The 1s electron does not give a peak. It is probably at an energy lower than -1253.6 eV and inaccessible with the x-radiation used in this experiment.

+ 1 pt for each correct assignment

(c)

$$\begin{aligned} \text{Energy difference between 3s and 3p} &= -IE_1 - (-IE_2) = -3.5 \text{ eV} - (-8.3 \text{ eV}) = 4.8 \text{ eV} \\ &= 7.7 \times 10^{-19} \text{ J} = \frac{hc}{\lambda} \end{aligned}$$

$$\therefore \lambda = \frac{hc}{E} = 258 \text{ nm} \quad \text{No partial points}$$

5. (total 6 pts)

Cr and Cu have anomalous electron configurations. Explain the reason.

(a) [3 pts] Cr: $[\text{Ar}] 4s^1 3d^5$ instead of $[\text{Ar}] 4s^2 3d^4$

(b) [3 pts] Cu: $[\text{Ar}] 4s^1 3d^{10}$ instead of $[\text{Ar}] 4s^2 3d^9$

(Answer)

(a) For Cr, the singly occupied 3d has lower energy than the doubly occupied 4s because of the repulsion between the doubly occupied electrons.

(b) As the atomic number increases, the energy of 3d decreases more rapidly than that of 4s because of the smaller shielding effect in 3d than in 4s. For Cu, the doubly occupied 3d has lower energy than the doubly occupied 4s.

6. (total 10 pts)

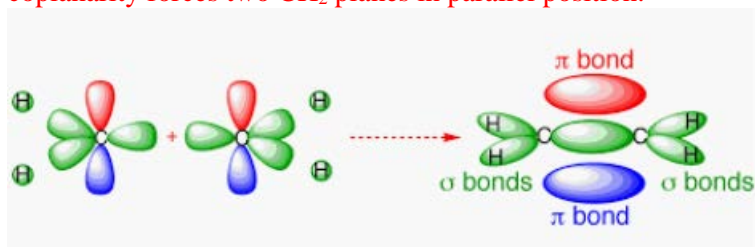
Provide answers with your rationale to the following questions.

(a) [4 pts] Consider a molecule ethylene, $\text{H}_2\text{C}=\text{CH}_2$ and let us label it as $\text{H}_a\text{H}_b\text{C}_1=\text{C}_2\text{H}_c\text{H}_d$. Since three points form a plane, we can think of two planes of $\text{H}_a\text{H}_b\text{C}_1$ and $\text{C}_2\text{H}_c\text{H}_d$. Determine whether these two planes are parallel or perpendicular each other by assigning the hybridization of each carbon atom.

(b) [6 pts] Now consider another molecule $\text{H}_2\text{C}=\text{C}=\text{CH}_2$, called allene, with labeling $\text{H}_a\text{H}_b\text{C}_1=\text{C}_M=\text{C}_2\text{H}_c\text{H}_d$. Determine whether $\text{H}_a\text{H}_b\text{C}_1$ and $\text{C}_2\text{H}_c\text{H}_d$ planes are parallel or perpendicular each other by assigning the hybridization of each carbon atom.

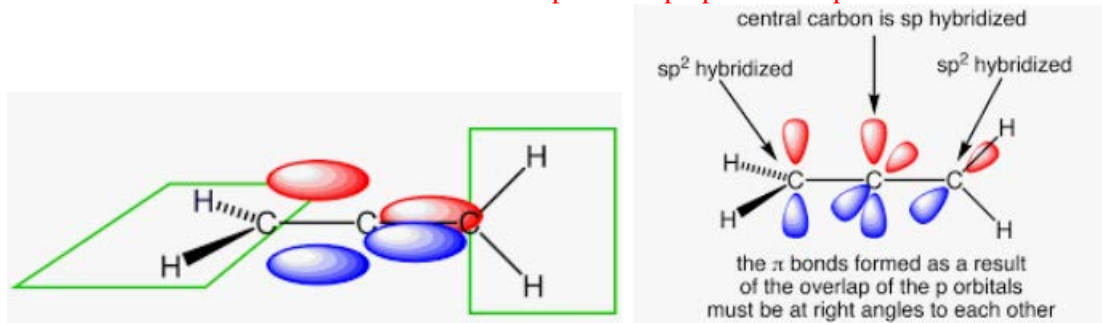
(Answer)

(a) Parallel. As illustrated below, each C in ethylene utilizes sp^2 hybridized orbitals to form sigma-bonds with C and two H atoms. Then the remaining p-orbitals should be coplanar to make pi-bonding interaction. This coplanarity forces two CH_2 planes in parallel position.



2 pts for correct answer and 2 pts for correct hybridization

(b) Perpendicular. The C_M atom needs two p-orbitals that are perpendicular each other to form two pi-bonds with C_1 and C_2 . This situation forces two CH_2 planes in perpendicular position as shown below.



2 pts for correct answer and 2 pts for correct hybridization, 2pts for correct explanation

7. (total 12 pts)

One electron addition to dioxygen (O_2) generates O_2^- (superoxide) and two electron addition to dioxygen generates O_2^{2-} (peroxide). These are called as “Reactive Oxygen Species” (ROS). In a biological system, ROS are harmful, so organisms have mechanisms to remove these. Answer the following questions.

(a) [3 pts] Draw the correlation diagrams of O_2 , O_2^- , O_2^{2-} . Consider only 2s and 2p orbital and z-axis is parallel to O-O bond.

(b) [3 pts] Are they paramagnetic or diamagnetic?

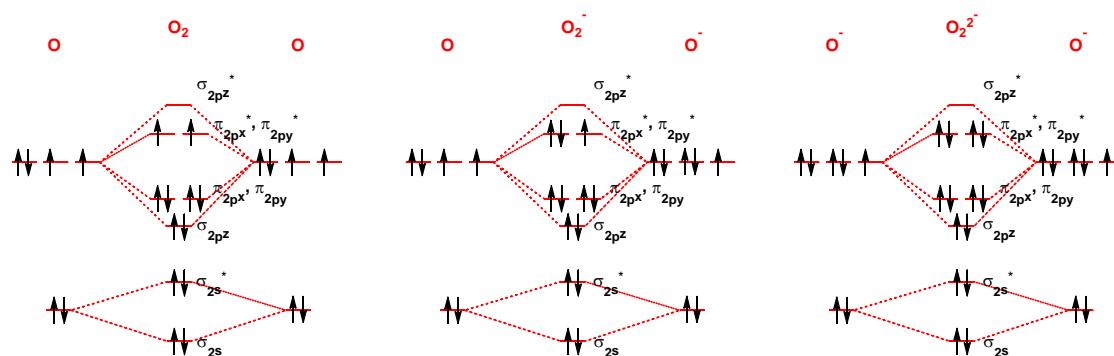
(c) [3 pts] In the biological system, some enzymes add two electrons to O_2 to cleave O=O double bond. Explain why.

(d) [3 pts] Compared to oxygen atom, are the ionization energies of these species higher or lower? Justify your answer using the correlation diagram in (a).

(Answer)

+1 pt for each species

(a)



(b) O_2 and O_2^- are paramagnetic, whereas O_2^{2-} is diamagnetic

(c) The bond orders of O_2 , O_2^- and O_2^{2-} are 2, 3/2 and 1, respectively. In terms of bond order, O_2^{2-} has the weakest O-O bond strength. So it can readily be dissociated.

(d) Those species have electrons in the antibonding orbital originated from the oxygen p-orbital (π_{2px}^* and π_{2py}^*). And this antibonding orbital has higher energy than that of the original p-orbital. So, they have lower ionization energies.

8. (total 6 pts)

What is the order of boiling points for the substances, NH_3 , H_2O , and HF . Explain the reason.

(Answer)

+2 pts: $\text{H}_2\text{O} > \text{HF} > \text{NH}_3$

+2 pts: H_2O can form 2 hydrogen bonds per molecule (2 H atoms and 2 lone pair electrons for H bond formation). HF and NH_3 can form only 1 hydrogen bond per molecule (1 H atom and 3 lone pair electrons for HF , 3 H atoms and 1 lone pair electrons for NH_3).

+2 pts: F has higher electronegativity than N.

9. (total 10 pts)

(a) [4 pts] Arrange the following substances in order of decreasing critical temperature (T_c): Ar, H_2 , Kr, CCl_3F

(b) [6 pts, each 3 pts] Which of the following substances should we expect to have the lower vapor pressure at a given temperature :

(1) CO_2 or SO_2

(2) CH_3OCH_3 or $\text{CH}_3\text{CH}_2\text{OH}$

(Answer)

(a)

CCl_3F is a polar molecule (strong dipole-dipole forces)

We expect that CCl_3F will have the highest T_c .

The remaining 3 substances can interact only by way of induced dipole-dipole (London dispersion force)

We would predict T_c to decrease in the order Kr(36 electrons), Ar(18 electrons), and H_2 (2 electrons).

+1 pt for each correct order

(b)

(1) London forces between SO_2 molecules should be greater than CO_2 .

Moreover, as SO_2 is polar but CO_2 is not.

Therefore SO_2 has the lower vapor pressure.

+1.5 pt for each correct order and +1.5 pt for each correct reason

(2) Molecular weights are equal.

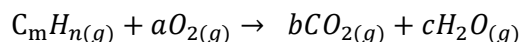
However, there will be strong hydrogen bonding in ethanol.

We expect ethanol to have the lower vapor pressure.

+1.5 pt for each correct order and +1.5 pt for each correct reason

10. (total 16 pts)

Consider a following combustion reaction in a closed container (10.0 atm, 22.4 L, 500 K):



Assume that all the molecules behave as ideal gases and a, b, c, m, and n are all positive integers. Initially, there were only C_mH_n and O_2 molecules inside the container. When 10.0 g of C_mH_n reacted fully with oxygen in the container, 33.0 g of CO_2 was formed. The total number of molecules inside the container remained the same after the combustion reaction, and no C_mH_n molecules remained after the reaction.

- (a) [2 pts] What is the total number of molecules inside the container?
- (b) [6 pts] What are the values of m and n? Round off the values into integers. (Hint: The total number of molecules remained the same after the reaction.)
- (c) [6 pts] Compute the number of O_2 , CO_2 , and H_2O molecules after the reaction.
- (d) [2 pts] Using the Van der Waals equation, calculate the partial pressure of water molecules after the reaction. Ignore interactions between water molecules and other types of molecules.

	a (atm L ² mol ⁻²)	b (L mol ⁻¹)
H ₂ O	5.464	0.03049

(Answer)

(a)

$$n = \frac{PV}{RT} = \frac{10.0 \text{ atm} \times 22.4L}{(0.08206 \text{ L} \cdot \text{atm} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}) \times 500K} = 5.45 \text{ mol}$$

No partial points

(b)

First, balance the number of carbon for the combustion reaction: $b = m$

Second, balance the number of hydrogen for the reaction: $c = n/2$

Finally, balance the number of oxygen for the reaction: $a = b + c/2 = m + n/4$

Since the number of molecules does not change after the reaction, $1+a=b+c$

$$\therefore 1 + m + \frac{n}{4} = m + \frac{n}{2}$$

$$n = 4$$

$$\text{Molar mass of } C_mH_n = m \times 12.0g \cdot \text{mol}^{-1} + n \times 1.01g \cdot \text{mol}^{-1} = (12.0m + 1.01n)g \cdot \text{mol}^{-1}$$

$$\text{Molar mass of } CO_2 = 44.0g \cdot \text{mol}^{-1}$$

From the reaction equation, we can deduce that:

$$(\text{number of } C_mH_n \text{ molecules consumed}) \times m = (\text{number of } CO_2 \text{ molecules formed})$$

$$\therefore \frac{10.0g \ C_mH_n}{(12.0m + 1.01n)} \times m = \frac{33.0g \ CO_2}{44.0g/mol}$$

By solving the equation, $m = 3.03 \rightarrow m = 3$ (m is a positive integer).

+ 3 pts for correct m , + 3 pts for correct n

(c)

The overall reaction is as follows:



Therefore, for every 1 C_3H_4 molecule consumed, 3 CO_2 molecules and 2 water molecules are formed.

$$\text{number of } H_2O \text{ molecules} = \frac{10.0g \ C_3H_4}{40.0g/mol} \times 2 = 0.500 \text{ mol } H_2O$$

$$\text{number of } CO_2 \text{ molecules} = \frac{10.0g \ C_3H_4}{40.0g/mol} \times 3 = 0.750 \text{ mol } CO_2$$

Since the overall number of molecules stays the same,

$$\text{number of } O_2 \text{ molecules} = 5.45 \text{ mol} - (0.500 \text{ mol } H_2O + 0.750 \text{ mol } CO_2) = 4.20 \text{ mol } O_2$$

+ 2 pts for each correct number of molecules

(d)

$$P_{H_2O} = \frac{n_{H_2O}RT}{V - n_{H_2O}b} - a \frac{n_{H_2O}^2}{V^2} = \frac{(0.500 \text{ mol}) \times (0.08206 \text{ L} \cdot \text{atm} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}) \times 500K}{22.4L - 0.500 \text{ mol} \times 0.03049L \text{ mol}^{-1}} - 5.464 \times \frac{(0.500 \text{ mol})^2}{(22.4L)^2}$$
$$= 0.914 \text{ atm}$$

which is only slightly lower than the ideal partial pressure (0.917 atm).

No partial points

Using the ideal gas law instead of the Van der Waals equation will not get any points.