

## 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
<b>1</b>	/10	<b>6</b>	/10	<b>/100</b>
<b>2</b>	/10	<b>7</b>	/12	
<b>3</b>	/10	<b>8</b>	/6	
<b>4</b>	/10	<b>9</b>	/10	
<b>5</b>	/6	<b>10</b>	/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](http://www.gencheminkaist.pe.kr).

**1. (total 10 pts)**

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

	IE <sub>1</sub>	IE <sub>2</sub>	IE <sub>3</sub>	IE <sub>4</sub>	IE <sub>5</sub>	IE <sub>6</sub>	IE <sub>7</sub>	IE <sub>8</sub>
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)

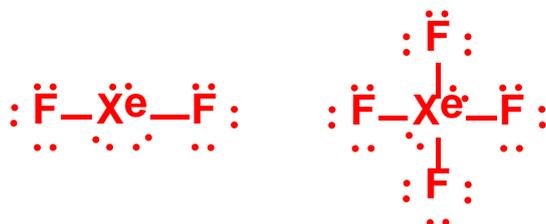
(b) [3 pts] IE<sub>8</sub> is significantly higher than IE<sub>7</sub>. Explain why.

**(Answer)**

IE<sub>8</sub> is the required energy to get rid of one electron from F<sup>7+</sup> 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 XeX<sub>2</sub> and XeX<sub>4</sub>. Draw the Lewis structure of each molecule, and predict their geometries using the VSEPR theory.

**(Answer)**



XeF<sub>2</sub> = linear structure, XeF<sub>4</sub> = 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)**

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

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

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

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

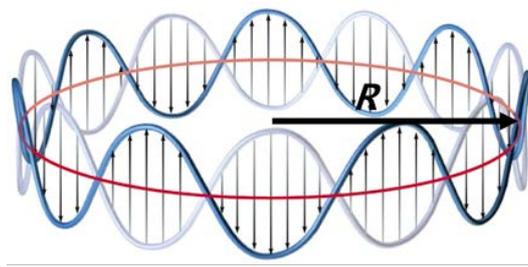
(c) The longest wavelength to promote the photoelectric effect for cesium occurs when the light energy matches the work function since

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

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

**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  $\lambda$  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  $\lambda$ . Compare the result with the de Broglie's hypothesis between  $p$  and  $\lambda$ .

**(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  $\lambda$  excited an electron from the 3s orbital to the 3p orbital.

Using the photoelectron spectroscopy data, calculate the value of  $\lambda$ .

#### (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  $-1253.6 \text{ eV}$  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)

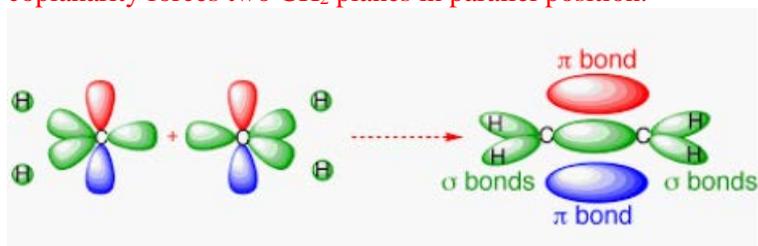
Provide answers with your rationale to the following questions.

(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.

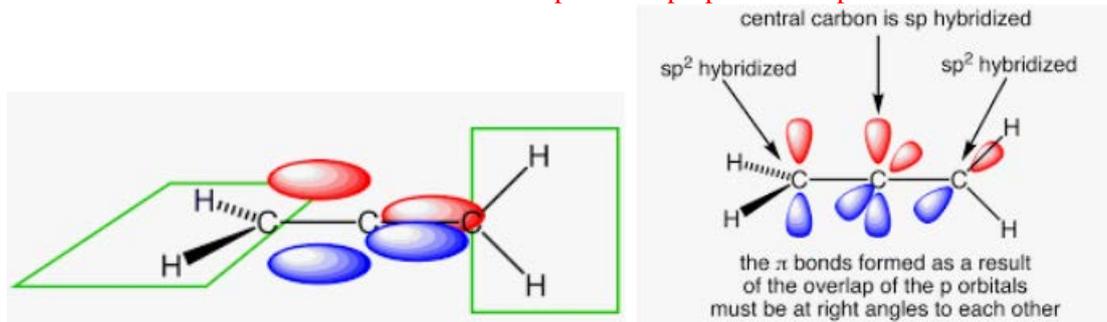
(Answer)

(a) Parallel. As illustrated below, each C in ethylene utilizes  $\text{sp}^2$  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  $\text{CH}_2$  planes in parallel position.



2 pts for correct answer and 2 pts for correct hybridization

(b) Perpendicular. The  $\text{C}_M$  atom needs two p-orbitals that are perpendicular each other to form two pi-bonds with  $\text{C}_1$  and  $\text{C}_2$ . This situation forces two  $\text{CH}_2$  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?

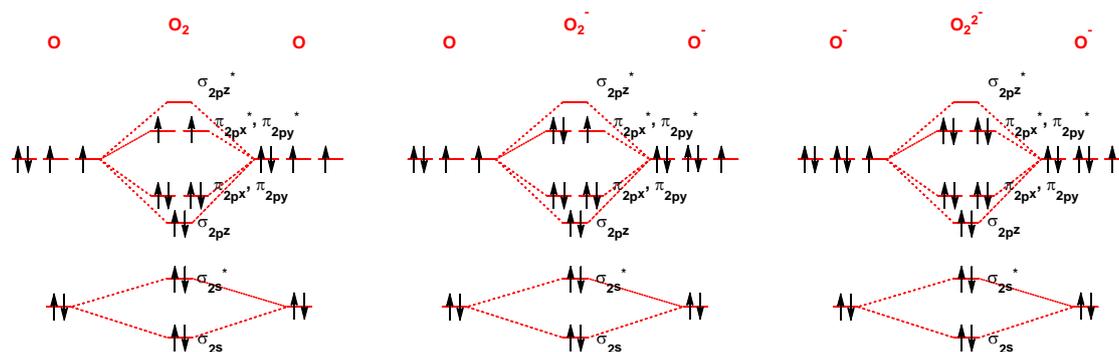
(c) [3 pts] In the biological system, some enzymes add two electrons to  $O_2$  to cleave O=O double bond. Explain why.

(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 ( $\pi_{2px}^*$  and  $\pi_{2py}^*$ ). 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,  $\text{NH}_3$ ,  $\text{H}_2\text{O}$ , and  $\text{HF}$ . Explain the reason.

**(Answer)**

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

+2 pts:  $\text{H}_2\text{O}$  can form 2 hydrogen bonds per molecule (2 H atoms and 2 lone pair electrons for H bond formation).  $\text{HF}$  and  $\text{NH}_3$  can form only 1 hydrogen bond per molecule (1 H atom and 3 lone pair electrons for  $\text{HF}$ , 3 H atoms and 1 lone pair electrons for  $\text{NH}_3$ ).

+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,  $\text{H}_2$ , Kr,  $\text{CCl}_3\text{F}$

(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)  $\text{CO}_2$  or  $\text{SO}_2$

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

**(Answer)**

(a)

$\text{CCl}_3\text{F}$  is a polar molecule (strong dipole-dipole forces)

We expect that  $\text{CCl}_3\text{F}$  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  $\text{H}_2$ (2 electrons).

+1 pt for each correct order

(b)

(1) London forces between  $\text{SO}_2$  molecules should be greater than  $\text{CO}_2$ .

Moreover, as  $\text{SO}_2$  is polar but  $\text{CO}_2$  is not.

Therefore  $\text{SO}_2$  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.

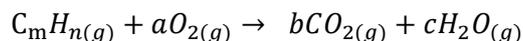
However, there will be strong hydrogen bonding in ethanol.

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 <sup>2</sup> mol <sup>-2</sup> )	b (L mol <sup>-1</sup> )
H <sub>2</sub> 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.

## 2019 Spring Semester Final Examination For General Chemistry I

**Date: June 12 (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
<b>1</b>	2x6/12	<b>7</b>	3+3+3+2/11	/100
<b>2</b>	3+2+1/6	<b>8</b>	3+2+4/9	
<b>3</b>	2+4+4/10	<b>9</b>	2x5/10	
<b>4</b>	2+4+4/10	<b>10</b>	3+3+4/10	
<b>5</b>	4+2/6	<b>11</b>	2+2+2+4/10	
<b>6</b>	4+2/6			

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### 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: **June 14 (Friday, 12: 00 ~ 14:00 p.m., 2 hrs)**
- 2) **Location: Room in Creative Learning Bldg. (E11)**

Class	Room	Class	Room	Class	Room
<i>A</i>	<i>301</i>	<i>D</i>	<i>406</i>	<i>G</i>	<i>411</i>
<i>B</i>	<i>302</i>	<i>E</i>	<i>409</i>		
<i>C</i>	<i>402</i>	<i>F</i>	<i>410</i>		

- 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)**

(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. The claim is permitted only on the period. Keep that in mind! A solution file with answers will be uploaded on **June 14** on the web.)

#### 2. Final Confirmation

- 1) Period: June 15 (Sat) –16 (Sun)
- 2) Procedure: During this period, you can check final score of the examination *on the website* again.

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**1. (total 12 pts, +2 pts for each correct answer and -0.5 pts for each wrong answer)** Please mark each of the following 6 questionnaires with 'T' when the statement is true and with 'F' when the statement is false.

(a) The best way of preparing 100 mL of  $1.0 \times 10^{-4}$  M aqueous solution of a compound with molar mass of  $100 \text{ g mol}^{-1}$  is weighing out corresponding amount of sample, transferring to 100 mL volumetric flask, dissolving with water and marking to the level.

**(Answer)**

F

(b)  $\text{Ca}^{2+}$  ion is known to be very inert to redox reaction. Therefore, the quantity of  $\text{Ca}^{2+}$  ion in aqueous solution cannot be measured the redox titration technique.

**(Answer)**

F

(c) A new protein whose molar mass is expected to be larger than  $20,000 \text{ g mol}^{-1}$  shows low solubility in water. Its molar mass can be determined with low error by measuring boiling point elevation.

**(Answer)**

F

(d) The equilibrium constant for the reaction  $\text{KOH(s)} + \text{CO}_2(\text{g}) \rightleftharpoons \text{KHCO}_3(\text{s})$  is known as  $6.0 \times 10^{15}$  at  $25^\circ\text{C}$ . In order to find out the pressure of  $\text{CO}_2(\text{g})$  at equilibrium, some amount of KOH and  $\text{KHCO}_3$  are placed in a closed evacuated container and allowed to reach equilibrium. But by mistake unknown amount of KOH and  $\text{KHCO}_3$  are added and thus the pressure of  $\text{CO}_2(\text{g})$  at equilibrium cannot be determined.

**(Answer)**

F

(e) The ideal gases reaction system  $\text{A}_2(\text{g}) + \text{B}_2(\text{g}) \rightleftharpoons 2 \text{AB}(\text{g})$  does not occur at  $T_1 \text{ K}$ . Thus,  $\text{A}_2(\text{g})$  and  $\text{B}_2(\text{g})$  are sealed in a flask at  $T_1 \text{ K}$  with partial pressure of  $P(\text{A}_2)$  and  $P(\text{B}_2)$  atm and the temperature is raised to  $T_2 \text{ K}$ . In this case, the equilibrium value of  $P(\text{AB})$  at  $T_2 \text{ K}$  can be calculated when the equilibrium constant for the reaction at  $T_2 \text{ K}$  is known.

**(Answer)**

T

(f) When we want to clean a flask by rinsing with 100 mL water, it is better way to rinse it twice with larger aliquot of 50 mL water than to rinse 4 times with smaller aliquot of 25 mL water.

**(Answer)**

F

## 2. (total 6 pts)

The vapor pressure of pure liquid CS<sub>2</sub> is 0.3914 atm at 20°C. When 40.0 g of rhombic sulfur is dissolved in 1.00 kg of CS<sub>2</sub>, the vapor pressure of CS<sub>2</sub> decreases to 0.3868 atm. Determine the molecular formula for the sulfur molecules dissolved in CS<sub>2</sub>. (The atomic mass of S is 32 g mol<sup>-1</sup>).

**(Answer) mole fraction 3 pts; molar mass 2 pts; S<sub>8</sub> 1 pt**

The change in the vapor pressure  $\Delta P$  is  $0.3868 - 0.3914 = -0.0046$  atm. The mole fraction of the sulfur present in the sulfur-CS<sub>2</sub> system is therefore

$$X_{\text{sulfur}} = -\frac{\Delta P}{P_{\text{CS}_2}^\circ} = -\frac{-0.0046 \text{ atm}}{0.3914 \text{ atm}} = 0.0117$$

The solution contains 1.00 kg of CS<sub>2</sub> which is 13.13 mol of CS<sub>2</sub>.<sup>7</sup> Hence

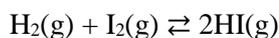
$$X_{\text{sulfur}} = 0.0117 = \frac{n_{\text{sulfur}}}{n_{\text{sulfur}} + n_{\text{CS}_2}} = \frac{n_{\text{sulfur}}}{n_{\text{sulfur}} + 13.13 \text{ mol}}$$

Solving for the chemical amount of sulfur gives 0.155 mol. Because this amount of sulfur is simultaneously 40.0 g of sulfur, the molar mass of sulfur as it exists in this solution is  $40.0 \text{ g}/0.155 \text{ mol} =$

$257 \text{ g mol}^{-1}$ . This is almost exactly eight times larger than  $32 \text{ g mol}^{-1}$ , the molar mass of S. The molecular formula of the sulfur in the solution must be  $\boxed{\text{S}_8}$ .

## 3. (total 10 pts)

(a) (2 pts) The equilibrium constant for the following reaction is 50.5 at 448°C.



Suppose that a vessel at this temperature contains 5.0M H<sub>2</sub>, 3.0M I<sub>2</sub>, and 1.0M HI. Is the mixture in equilibrium?

**(Answer)**

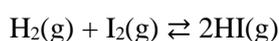
The reaction quotient Q is

$$Q = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = \frac{(1.0)^2}{(5.0)(3.0)} = 0.0667 < K$$

To attain equilibrium, the system must consume H<sub>2</sub> and I<sub>2</sub> to produce additional HI. **No equilibrium.**

(b) (4 pts) Determine the concentrations of H<sub>2</sub>, I<sub>2</sub> and HI when the mixture described in (a) comes to equilibrium.

**(Answer) law of mass action 1 pt; concentrations 3 pts**



5.0M    3.0M    1.0M

-x        -x        +2x

Equilibrium 5.0-x    3.0-x    1.0+2x

$$K = \frac{[HI]^2}{[H_2][I_2]} = \frac{(1.0 + 2x)^2}{(5.0 - x)(3.0 - x)} = 50.5$$

$$46.5x^2 - 408x + 756.5 = 0$$

$$x = \frac{408 \pm 160.48}{93.0} = 2.66M$$

$$[H_2] = 5.0 - 2.66 = 2.34M$$

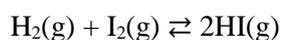
$$[I_2] = 3.0 - 2.66 = 0.34M$$

$$[HI] = 1.0 + 2 \times 2.66 = 6.32M$$

(c) (4 pts) What would happen if the concentration of HI at equilibrium were suddenly increased to 10.0M ?  
Determine the equilibrium concentrations of H<sub>2</sub>, I<sub>2</sub> and HI.

**(Answer) law of mass action 1 pt; concentrations 3 pts**

There would be a move toward a new equilibrium



2.34M 0.34M 10.0M

at equilibrium 2.34+x 0.34+x 10.0-2x

$$K = \frac{[HI]^2}{[H_2][I_2]} = \frac{(10.0 - 2x)^2}{(2.34 + x)(0.34 + x)} = 50.5$$

$$x = 0.315$$

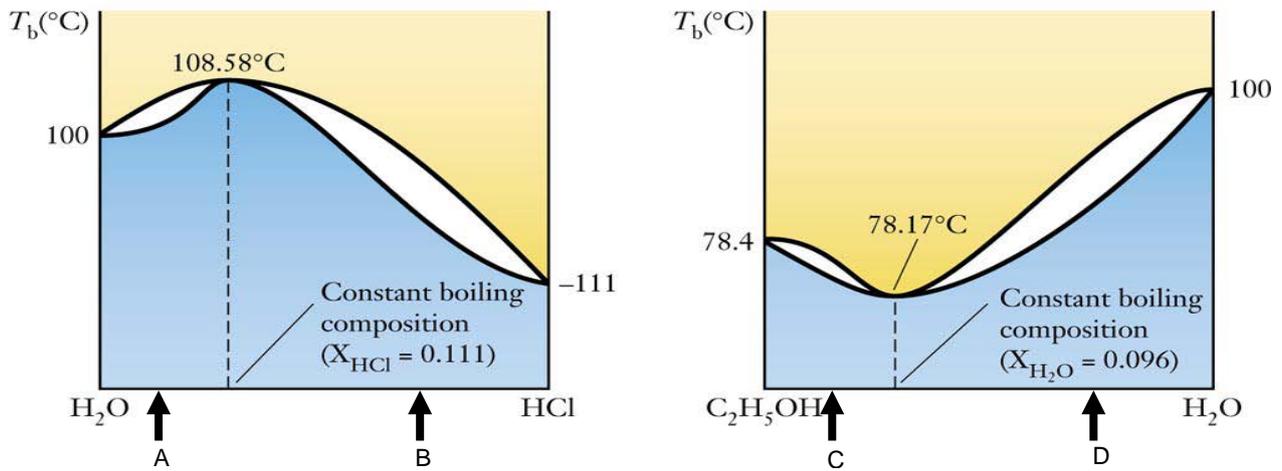
$$[H_2] = 2.34 + x = 2.66M$$

$$[I_2] = 0.34 + x = 0.66M$$

$$[HI] = 10 - 2x = 9.37M$$

The stress of having too much HI is relieved.

4. (total 10 pts) Next figures show dependence of boiling temperature on the mole fraction of the substance.



(a) (2 pts) What is azeotrope?

**(Answer)**

Liquid solution of two volatile components whose vapor has the same composition

(b) (4 pts) Which interaction is stronger?

H<sub>2</sub>O-HCl or H<sub>2</sub>O-H<sub>2</sub>O, HCl-HCl

**(Answer) 2 pts**

H<sub>2</sub>O-HCl > H<sub>2</sub>O-H<sub>2</sub>O, HCl-HCl

H<sub>2</sub>O-C<sub>2</sub>H<sub>5</sub>OH or H<sub>2</sub>O-H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH-C<sub>2</sub>H<sub>5</sub>OH

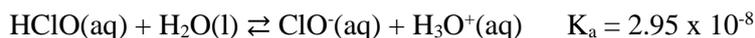
**(Answer) 2 pts**

H<sub>2</sub>O-C<sub>2</sub>H<sub>5</sub>OH < H<sub>2</sub>O-H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH-C<sub>2</sub>H<sub>5</sub>OH

(c) (4 pts) What are the last compositions during fractional distillation when the solution has the composition of A, B, C, or D?

**(Answer) 1 pt for each**

Mixture composition	A	B	C	D
Last composition	H <sub>2</sub> O	HCl	azeotrope	azeotrope

**5. (total 6 pts)**

(a) (4 pts) In this reaction, calculate the equilibrium concentrations of  $\text{H}_3\text{O}^+$ ,  $\text{ClO}^-$  and  $\text{HClO}$  in a 0.50 M solution of hypochlorous acid,  $\text{HClO}(\text{aq})$ .

**(Answer) law of mass action 1 pts; concentrations 3 pts**

Reaction	$\text{HClO}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{ClO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$		
Initial	0.5	0	0
Change	- x	+ x	+ x
Equilibrium	$0.5 - x$	x	x

$$K_a = \frac{[\text{ClO}^-][\text{H}_3\text{O}^+]}{[\text{HClO}]} \quad 2.95 \times 10^{-8} = \frac{x^2}{0.5-x}$$

Assume x is much smaller than the initial  $[\text{HClO}]$ .  $\therefore 0.50 - x \approx 0.50$

$$x^2 = 0.5 \times 2.95 \times 10^{-8} = 1.475 \times 10^{-8} \quad x = 1.21 \times 10^{-4}$$

**Equilibrium conc.  $[\text{H}_3\text{O}^+] = [\text{ClO}^-] = 1.21 \times 10^{-4} \text{ mol L}^{-1}$**

**$[\text{HClO}] = 0.5 - 1.21 \times 10^{-4} = 0.5 \text{ mol L}^{-1}$**

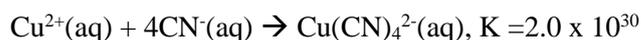
(b) (2 pts) What is the pH of this solution?

**(Answer)**

$$\text{pH} = -\log [\text{H}_3\text{O}^+] = -\log (1.21 \times 10^{-4}) = 3.92$$

**6. (total 6 pts)**

Calculate the concentration of  $\text{Cu}^{2+}(\text{aq})$  in a solution that contains 0.020 mol of  $\text{CuCl}_2$  and 0.100 mol of  $\text{NaCN}$  in 1.0 L.  $\text{p}K_a$  value of  $\text{HCN}$  is 9.21.

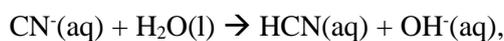


(Hint. Do not overlook the reaction of  $\text{CN}^-$  with water to give  $\text{HCN}$ )

**(Answer) 4 pts for the procedure, 2 pts for the answer**

The  $\text{Cu}^{2+}(\text{aq})$  and  $\text{CN}^-(\text{aq})$  will combine to form a complex ion based on following given chemical equation.

First, We can assume that nearly all of the  $\text{Cu}^{2+}$  ion is complexed based on very large  $K_f$  value. Then,  $[\text{Cu}(\text{CN})_4^{2-}]$  is 0.020 M and  $[\text{CN}^-]$  is 0.020 M (0.100 M – 0.080 M). After that, hydrolysis of water by  $\text{CN}^-$  can be considered.



$$[\text{HCN}][\text{OH}^-]/[\text{CN}^-] = K_w/K_a = 1.0 \times 10^{-14}/6.17 \times 10^{-10} = 1.62 \times 10^{-5}$$

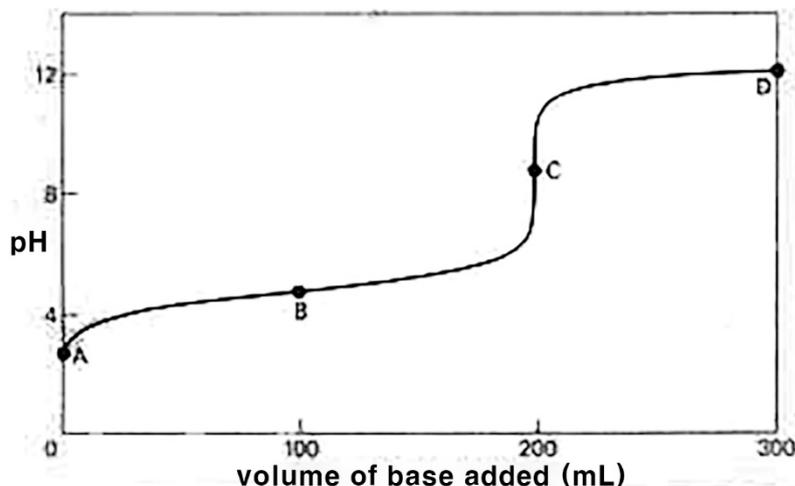
This reaction lowers the concentration of  $\text{CN}^-(\text{aq})$  from 0.020 M. Let x equal the concentration of  $\text{CN}^-$  that reacts in this way. Then

$$[\text{HCN}][\text{OH}^-]/[\text{CN}^-] = 1.62 \times 10^{-5} = x^2 / (0.020 - x), \quad x = 5.61 \times 10^{-4} \text{ M.}$$

A better value for the equilibrium concentration of  $\text{CN}^-$  is therefore  $0.020 - 5.61 \times 10^{-4} = 0.0194 \text{ M}$ . Put this value into  $K_f$  expression and solve for  $[\text{Cu}^{2+}]$

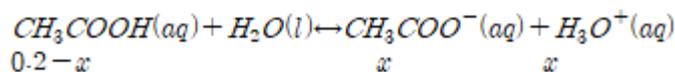
$$[\text{Cu}(\text{CN})_4^{2-}]/[\text{Cu}^{2+}][\text{CN}^-]^4 = 2.0 \times 10^{30} = (0.020)/[\text{Cu}^{2+}](0.0194)^4, \quad [\text{Cu}^{2+}] = 7.0 \times 10^{-26}$$

7. (total 11 pts) To 50 mL of 0.20 M acetic acid ( $K_a = 1.76 \times 10^{-5}$ ) at 25 °C, a chemist adds a 0.050 M solution of NaOH in the following amounts of (a)-(d). Compute the pH for each point.



(a) (3 pts) 0 mL

(Answer)



0.2 - x

x

x

$$\frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]} = \frac{x^2}{0.2 - x} = K_a = 1.76 \times 10^{-5}$$

$$0.2 - x \approx 0.2$$

$$x^2 = 0.2 \times K_a = 0.2(1.76 \times 10^{-5})$$

$$x = 1.88 \times 10^{-3} M$$

$$pH = -\log[H_3O^+] = -\log(0.00188) = 2.73$$

(b) (3 pts) 100 mL

(Answer)

$$\frac{0.2 \text{ mol } CH_3COOH}{L} \times 50 \text{ mL} \times \frac{1 L}{1000 \text{ mL}} = 0.01 \text{ mol } CH_3COOH$$

$$\frac{0.05 \text{ mol } OH^-}{L} \times 100 \text{ mL} \times \frac{1 L}{1000 \text{ mL}} = 0.005 \text{ mol } OH^-$$

In the total volume 150 mL, we now have 0.005 mol less of  $CH_3COOH$  and 0.005 mol more of  $CH_3COO^-$

$$[CH_3COOH]_0 = \frac{(0.01 - 0.005) \text{ mol}}{0.15 L} = 0.033 M$$

$$[CH_3COO^-]_0 = \frac{(0 + 0.005) \text{ mol}}{0.15 L} = 0.033 M$$

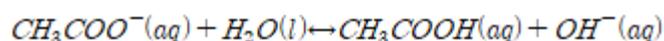
$$pH = pK_a + \log \frac{[CH_3COO^-]_0}{[CH_3COOH]_0} = 4.75 + \log 1 = 4.75$$

The titration has reached the half-equivalence point.

(c) (3 pts) 200 mL

**(Answer)**

0.01mol of  $\text{OH}^-$  has reacted with 0.01mol of  $\text{CH}_3\text{COOH}$ . Neutralization is complete; and now in a total volume of 250ml, there is 0.01mole of  $\text{CH}_3\text{COO}^-$  that undergoes hydrolysis to produce  $\text{OH}^-$



$$[\text{CH}_3\text{COO}^-]_0 = \frac{0.01\text{mol}}{1.25\text{L}} = 0.04\text{M}$$

$$K_b = \frac{[\text{CH}_3\text{COOH}][\text{OH}^-]}{[\text{CH}_3\text{COO}^-]} = \frac{x^2}{0.04 - x} = 5.7 \times 10^{-10}$$

$$x^2 = 0.04(5.7 \times 10^{-10})$$

$$x = 4.77 \times 10^{-6} = [\text{OH}^-]$$

$$[\text{H}_3\text{O}^+] = \frac{K_w}{[\text{OH}^-]} = \frac{1.0 \times 10^{-14}}{4.77 \times 10^{-6}} = 2.1 \times 10^{-9}$$

$$\text{pH} = -\log[\text{H}_3\text{O}^+] = 8.68$$

(d) (2 pts) 300 mL

**(Answer)**

$$\frac{0.05\text{mol OH}^-}{\text{L}} \times 0.1\text{L} = 0.005\text{mol OH}^-$$

$$[\text{OH}^-] = \frac{0.005\text{mol OH}^-}{0.35\text{L}} = 0.0143\text{M}$$

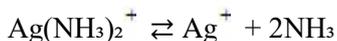
$$\text{pH} = -\log[\text{H}_3\text{O}^+] = -\log\left[\frac{K_w}{[\text{OH}^-]}\right] = -\log(7.0 \times 10^{-13}) = 12.15$$

### 8. (total 9 pts)

(a) (3 pts) What is the concentration of  $\text{Ag}^+$  (aq) ion in 0.010 M  $\text{AgNO}_3$  with 1.0 M  $\text{NH}_3$ ? The  $K_f$  for  $\text{Ag}(\text{NH}_3)_2^+$  ion is  $1.7 \times 10^7$ .

**(Answer)**

$\text{Ag}^+$  (aq) reacts completely to form  $\text{Ag}(\text{NH}_3)_2^+$ , then this complex ion subsequently dissociates to give a small amount of  $\text{Ag}^+$  (aq). We initially have 0.01mol  $\text{Ag}^+$  (aq) from  $\text{AgNO}_3$ . This reacts to give 0.01mol  $\text{Ag}(\text{NH}_3)_2^+$ , leaving (1.0-0.01)mol  $\text{NH}_3$ . We now look at equilibrium for the dissociation of  $\text{Ag}(\text{NH}_3)_2^+$ .



Starting 0.01 0 1.0

Change  $-x$   $x+2x$

Equilibrium 0.01- $x$   $x$  1.0+2 $x$

$$\frac{[\text{Ag}^+][\text{NH}_3]^2}{[\text{Ag}(\text{NH}_3)_2^+]} = K_d = \frac{1}{K_f}$$

$$\frac{x(1.0 + 2x)^2}{0.01 - x} = \frac{1}{1.7 \times 10^7}$$

$$\frac{x}{0.01} \approx 5.9 \times 10^{-8}$$

$$x = 5.9 \times 10^{-10} \text{ M}$$

(b) (2 pts) Will silver chloride (AgCl) precipitate from a solution that is 0.01M AgNO<sub>3</sub> and 0.01M NaCl if it is also with 1.0 M NH<sub>3</sub>? K<sub>sp</sub> for AgCl is 1.8 x 10<sup>-10</sup>.

**(Answer)**

$$\text{Ion product} = [\text{Ag}^+][\text{Cl}^-]$$

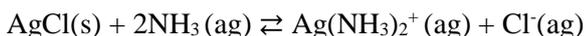
$$= (5.9 \times 10^{-10})(0.01)$$

$$= 5.9 \times 10^{-12}$$

Since the ion product is smaller than K<sub>sp</sub>=1.8 × 10<sup>-10</sup>, **no precipitate should form.**

(c) (4 pts) Calculate the molar solubility of AgCl in 1.0 M NH<sub>3</sub> at 25 °C.

**(Answer)**



Starting 1.0 0 0

Change -2χ +χ +χ

Equilibrium 1.0-2χ χ χ

$$\frac{[\text{Ag}(\text{NH}_3)_2^+][\text{Cl}^-]}{[\text{NH}_3]^2} = [\text{Ag}^+][\text{Cl}^-] \frac{[\text{Ag}(\text{NH}_3)_2^+]}{[\text{Ag}^+][\text{NH}_3]^2}$$

$$= K_{sp} \times K_f$$

$$= (1.8 \times 10^{-10})(1.7 \times 10^7)$$

$$= 3.1 \times 10^{-3}$$

K=

$$\frac{x^2}{(1.0 - 2x)^2} = 3.1 \times 10^{-3}$$

$$\frac{x}{(1.0 - 2x)} = 0.056$$

$$x = 0.056(1.0 - 2x) = 0.056 - 0.11x$$

$$x = \frac{0.056}{1.11} = 0.05$$

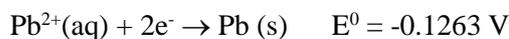
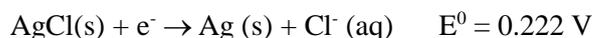
Since χ equals the concentration of Ag(NH<sub>3</sub>)<sub>2</sub><sup>+</sup> and most of the silver in solution will be in the form of this complex, **the molar solubility of AgCl equals 0.05M.**



10. (total 10 pts) Nupjuki decides to measure the solubility of lead sulfate in water and sets up the electrochemical cell.

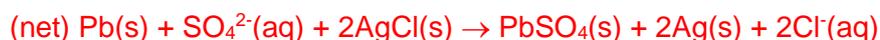
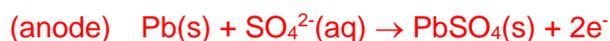


At 25°C, Nupjuki finds the cell potential to be 0.546 V, and from the textbook Nupjuki also finds



(a) (3 pts) What are the electrochemical formula of anode, cathode, and net reactions?

**(Answer)**



(b) (3 pts) Calculate the  $E^0$  of anode, cathode, and total cell.

**(Answer)**

Using Nernst equation,

$$E_{\text{cell}} = E^0_{\text{cell}} - 0.0592/n \log_{10}Q$$

where  $n=2$ , and  $Q = [\text{Cl}^-]^2/[\text{SO}_4^{2-}] = (1.00)^2 / 0.05 = 20$ . Also  $E_{\text{cell}}$  is measured as 0.546 V.

Thus,

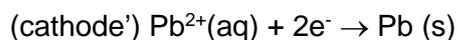
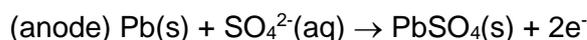
$$E_{\text{cell}}^0 = E_{\text{cell}} + 0.0592/n \log_{10}Q = 0.546 + 0.0385 = 0.5845 \text{ V}$$

Since,  $E_{\text{cell}}^0 = E^0_{\text{cathode}} - E^0_{\text{anode}}$ , and  $E^0_{\text{cathode}} = 0.222 \text{ V}$ ,  $E^0_{\text{anode}}$  becomes  $-0.3625 \text{ V}$ .

(c) (4 pts) What does he find for the  $K_{\text{sp}}$  of  $\text{PbSO}_4$ ?

**(Answer) reaction pair 1 pt; Ecell 1 pt; Ksp 2 pts**

We now consider another redox reaction pair of



Here the  $E^0_{\text{cell}} = -0.1264 - (-0.3625) = 0.2361 \text{ V}$ , which leads to

$$\Delta G^0_{\text{cell}} = -nFE^0_{\text{cell}} = -(2 \text{ mol})(96,500 \text{ C mol}^{-1})(0.2361 \text{ V}) = -45.5673 \text{ kJ}$$

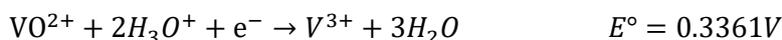
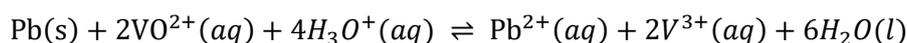
Thus, the  $\Delta G^0$  of the dissolution reaction of  $\text{PbSO}_4(\text{s})$  is 45.5673 kJ, and the equilibrium constant becomes

$$\Delta G^0 = -RT \ln K_{\text{sp}}$$

$$K_{\text{sp}} = \exp(-\Delta G^0/RT) = \exp\{-45567.3 \text{ J} / (8.314 \cdot 298.15)\} = 1.04 \times 10^{-8}$$

**11. (total 10 pts)**

Consider a following equilibrium in a galvanic cell at 25°C:



(a) (2 pts) Calculate  $E^\circ$  for the cell.

**(Answer)**

$$E^\circ = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = 0.3361\text{V} - (-0.1263\text{V}) = 0.4624\text{V} \dots + 2 \text{ pts}$$

(b) (2 pts) Calculate  $\Delta G^\circ$  for the cell.

**(Answer)**

$$\Delta G^\circ = -nFE^\circ = -(2) \times (96485\text{C} \cdot \text{mol}^{-1}) \times (0.4624\text{V}) = -89.23 \text{ kJmol}^{-1} \dots + 2 \text{ pts}$$

(c) (2 pts) Calculate the equilibrium constant for the cell.

**(Answer)**

$$\Delta G^\circ = -RT \ln K \quad K = \exp\left(\frac{-\Delta G^\circ}{RT}\right)$$

$$K = \exp\left(\frac{89230\text{J} \cdot \text{mol}^{-1}}{(8.314\text{J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1})(298.15\text{K})}\right) = 4.298 \times 10^{15} \dots + 2 \text{ pts}$$

(d) (4 pts) Suppose  $[\text{Pb}^{2+}] = 1.0 \times 10^{-2} \text{ M}$ ,  $[\text{VO}^{2+}] = 0.10 \text{ M}$ ,  $[\text{V}^{3+}] = 1.0 \times 10^{-5} \text{ M}$ , and the measured cell potential  $E = 0.640 \text{ V}$ . Calculate the pH of the solution in the cell.

**(Answer)**

$$E = E^\circ - \frac{RT}{nF} \ln Q = E^\circ - \frac{0.0592}{n} \log_{10} Q$$

For the anode reaction:

$$E = (-0.1263\text{V}) - \frac{0.0592}{2} \log_{10} \left( \frac{1}{[\text{Pb}^{2+}]} \right) = -0.1263 - \frac{0.0592}{2} \log \left( \frac{1}{1.0 \times 10^{-2}} \right) \\ = -0.1855\text{V} \dots + 1 \text{ pt}$$

For the cathode reaction:

$$E = E_{\text{cathode}} - E_{\text{anode}} = E_{\text{cathode}} - (-0.1855\text{V}) = 0.640\text{V}$$

$$\therefore E_{\text{cathode}} = 0.640\text{V} - 0.1855\text{V} = 0.4545\text{V} \dots + 1 \text{ pt}$$

$$0.4545\text{V} = E^\circ_{\text{cathode}} - \frac{0.0592}{n} \log \left( \frac{[\text{V}^{3+}]}{[\text{VO}^{2+}][\text{H}_3\text{O}^+]^2} \right) = 0.3361\text{V} - \frac{0.0592}{1} \log \left( \frac{1.0 \times 10^{-5}}{0.10 \times [\text{H}_3\text{O}^+]^2} \right)$$

$$\log \left( \frac{[\text{H}_3\text{O}^+]^2}{1.0 \times 10^{-4}} \right) = 2$$

$$[\text{H}_3\text{O}^+]^2 = 1.0 \times 10^{-4} \times 10^2 = 1.0 \times 10^{-2} \quad \therefore [\text{H}_3\text{O}^+] = 0.10\text{M}$$

$$\text{pH} = -\log(0.10\text{M}) = 1.0 \dots 2 \text{ pts}$$

## 2019 Spring Semester Final Examination For General Chemistry I

**Date:** June 12 (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
<b>1</b>	/12	<b>7</b>	/11	<b>/100</b>
<b>2</b>	/6	<b>8</b>	/9	
<b>3</b>	/10	<b>9</b>	/10	
<b>4</b>	/10	<b>10</b>	/10	
<b>5</b>	/6	<b>11</b>	/10	
<b>6</b>	/6			

\*\* This paper consists of 13 sheets with 11 problems (pages 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.

(채점 답안지 분배 및 이의신청 일정)

#### 1. Period, Location, and Procedure

- 1) Return and Claim Period: **June 14 (Friday, 12: 00 ~ 14:00 p.m., 2 hrs)**
- 2) **Location: Room in Creative Learning Bldg. (E11)**

Class	Room	Class	Room	Class	Room
<i>A</i>	<i>301</i>	<i>D</i>	<i>406</i>	<i>G</i>	<i>411</i>
<i>B</i>	<i>302</i>	<i>E</i>	<i>409</i>		
<i>C</i>	<i>402</i>	<i>F</i>	<i>410</i>		

- 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)

(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. The claim is permitted only on the period. Keep that in mind! A solution file with answers will be uploaded on **June 14** on the web.)

#### 2. Final Confirmation

- 1) Period: June 15 (Sat) –16 (Sun)
- 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](http://www.gencheminkaist.pe.kr).

**1. (total 12 pts, +2 pts for each correct answer and -0.5 pts for each wrong answer)** Please mark each of the following 6 questionnaires with 'T' when the statement is true and with 'F' when the statement is false.

(a) The best way of preparing 100 mL of  $1.0 \times 10^{-4}$  M aqueous solution of a compound with molar mass of  $100 \text{ g mol}^{-1}$  is weighing out corresponding amount of sample, transferring to 100 mL volumetric flask, dissolving with water and marking to the level.

**(Answer)**

(b)  $\text{Ca}^{2+}$  ion is known to be very inert to redox reaction. Therefore, the quantity of  $\text{Ca}^{2+}$  ion in aqueous solution cannot be measured the redox titration technique.

**(Answer)**

(c) A new protein whose molar mass is expected to be larger than  $20,000 \text{ g mol}^{-1}$  shows low solubility in water. Its molar mass can be determined with low error by measuring boiling point elevation.

**(Answer)**

(d) The equilibrium constant for the reaction  $\text{KOH(s)} + \text{CO}_2(\text{g}) \rightleftharpoons \text{KHCO}_3(\text{s})$  is known as  $6.0 \times 10^{15}$  at  $25^\circ\text{C}$ . In order to find out the pressure of  $\text{CO}_2(\text{g})$  at equilibrium, some amount of KOH and  $\text{KHCO}_3$  are placed in a closed evacuated container and allowed to reach equilibrium. But by mistake unknown amount of KOH and  $\text{KHCO}_3$  are added and thus the pressure of  $\text{CO}_2(\text{g})$  at equilibrium cannot be determined.

**(Answer)**

(e) The ideal gases reaction system  $\text{A}_2(\text{g}) + \text{B}_2(\text{g}) \rightleftharpoons 2 \text{AB}(\text{g})$  does not occur at  $T_1 \text{ K}$ . Thus,  $\text{A}_2(\text{g})$  and  $\text{B}_2(\text{g})$  are sealed in a flask at  $T_1 \text{ K}$  with partial pressure of  $P(\text{A}_2)$  and  $P(\text{B}_2)$  atm and the temperature is raised to  $T_2 \text{ K}$ . In this case, the equilibrium value of  $P(\text{AB})$  at  $T_2 \text{ K}$  can be calculated when the equilibrium constant for the reaction at  $T_2 \text{ K}$  is known.

**(Answer)**

(f) When we want to clean a flask by rinsing with 100 mL water, it is better way to rinse it twice with larger aliquot of 50 mL water than to rinse 4 times with smaller aliquot of 25 mL water.

**(Answer)**

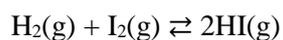
**2. (total 6 pts)**

The vapor pressure of pure liquid CS<sub>2</sub> is 0.3914 atm at 20°C. When 40.0 g of rhombic sulfur is dissolved in 1.00 kg of CS<sub>2</sub>, the vapor pressure of CS<sub>2</sub> decreases to 0.3868 atm. Determine the molecular formula for the sulfur molecules dissolved in CS<sub>2</sub>. (The atomic mass of S is 32 g mol<sup>-1</sup>).

**(Answer)**

**3. (total 10 pts)**

(a) [2 pts] The equilibrium constant for the following reaction is 50.5 at 448°C.



Suppose that a vessel at this temperature contains 5.0 M H<sub>2</sub>, 3.0 M I<sub>2</sub>, and 1.0 M HI. Is the mixture in equilibrium?

**(Answer)**

(b) [4 pts] Determine the concentrations of H<sub>2</sub>, I<sub>2</sub> and HI when the mixture described in (a) comes to equilibrium.

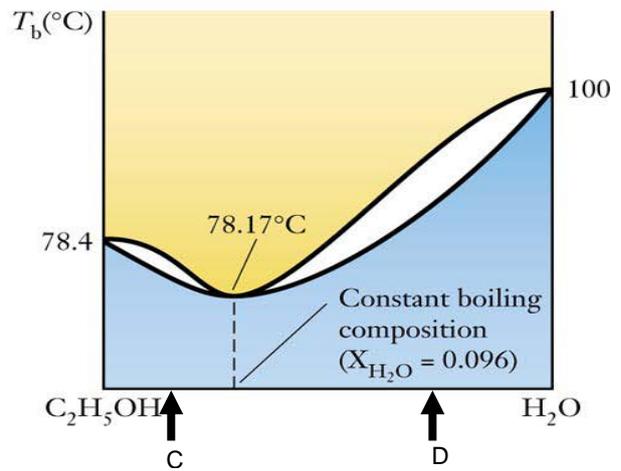
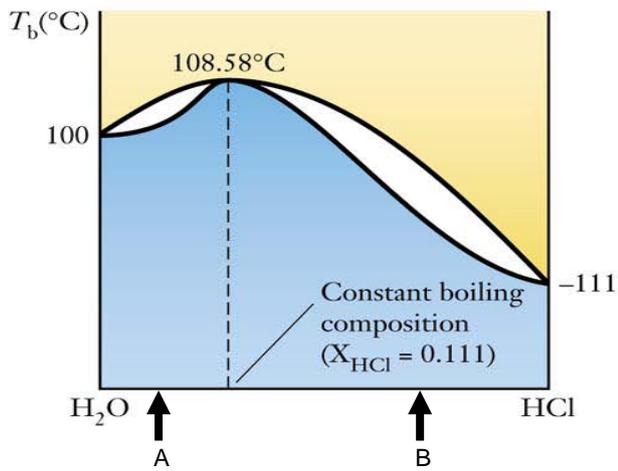
**(Answer)**

(c) [4 pts] What would happen if the concentration of HI at equilibrium were suddenly increased to 10.0 M?

Determine the equilibrium concentrations of H<sub>2</sub>, I<sub>2</sub> and HI.

**(Answer)**

4. (total 10 pts) Next figures show dependence of boiling temperature on the mole fraction of the substance.



(a) [2 pts] What is azeotrope?

(Answer)

(b) [4 pts] Which interaction is stronger?

H<sub>2</sub>O-HCl or H<sub>2</sub>O-H<sub>2</sub>O, HCl-HCl

(Answer)

H<sub>2</sub>O-C<sub>2</sub>H<sub>5</sub>OH or H<sub>2</sub>O-H<sub>2</sub>O, C<sub>2</sub>H<sub>5</sub>OH-C<sub>2</sub>H<sub>5</sub>OH

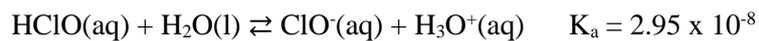
(Answer)

(c) [4 pts] What are the last compositions during fractional distillation when the solution has the composition of A, B, C, or D?

(Answer)

Mixture composition	A	B	C	D
Last composition				

**5. (total 6 pts)**



(a) [4 pts] In this reaction, calculate the equilibrium concentrations of  $\text{H}_3\text{O}^+$ ,  $\text{ClO}^-$  and  $\text{HClO}$  in a 0.50 M solution of hypochlorous acid,  $\text{HClO}(\text{aq})$ .

**(Answer)**

(b) [2 pts] What is the pH of this solution?

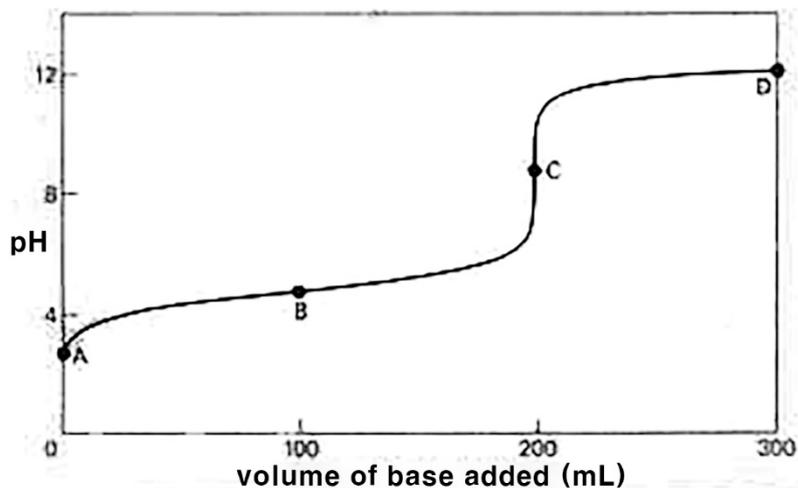
**(Answer)**

**6. (total 6 pts)** Calculate the concentration of  $\text{Cu}^{2+}(\text{aq})$  in a solution that contains 0.020 mol of  $\text{CuCl}_2$  and 0.100 mol of  $\text{NaCN}$  in 1.0 L.  $\text{p}K_a$  value of  $\text{HCN}$  is 9.21. (Hint. Do not overlook the reaction of  $\text{CN}^-$  with water to give  $\text{HCN}$ )



**(Answer)**

7. (total 11 pts) To 50 mL of 0.20 M acetic acid ( $K_a = 1.76 \times 10^{-5}$ ) at 25 °C, a chemist adds a 0.050 M solution of NaOH in the following amounts of (a)-(d). Compute the pH for each point.



(a) [3 pts] 0 mL

(Answer)

(b) [3 pts] 100 mL

(Answer)

(c) [3 pts] 200 mL

(Answer)

(d) [2 pts] 300 mL

(Answer)

**8. (total 9 pts)**

(a) [3 pts] What is the concentration of  $\text{Ag}^+$  (aq) ion in 0.010 M  $\text{AgNO}_3$  with 1.0 M  $\text{NH}_3$ ? The  $K_f$  for  $\text{Ag}(\text{NH}_3)_2^+$  ion is  $1.7 \times 10^7$ .

**(Answer)**

(b) [2 pts] Will silver chloride ( $\text{AgCl}$ ) precipitate from a solution that is 0.01M  $\text{AgNO}_3$  and 0.01M  $\text{NaCl}$  if it is also with 1.0 M  $\text{NH}_3$ ?  $K_{sp}$  for  $\text{AgCl}$  is  $1.8 \times 10^{-10}$ .

**(Answer)**

(c) [4 pts] Calculate the molar solubility of  $\text{AgCl}$  in 1.0 M  $\text{NH}_3$  at 25 °C.

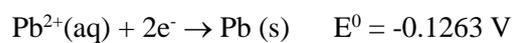
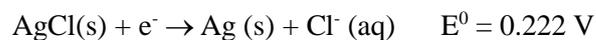
**(Answer)**



**10. (total 10 pts)** Nupjuki decides to measure the solubility of lead sulfate in water and sets up the electrochemical cell.



At 25°C, Nupjuki finds the cell potential to be 0.546 V, and from the textbook Nupjuki also finds



(a) [3 pts] What are the electrochemical formula of anode, cathode, and net reactions?

**(Answer)**

(b) [3 pts] Calculate the  $E^0$  of anode, cathode, and total cell.

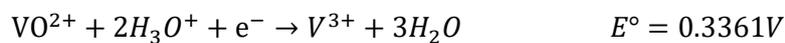
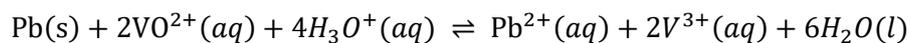
**(Answer)**

(c) [4 pts] What does he find for the  $K_{\text{sp}}$  of  $\text{PbSO}_4$ ?

**(Answer)**

**11. (total 10 pts)**

Consider a following equilibrium in a galvanic cell at 25°C:



(a) [2 pts] Calculate  $E^\circ$  for the cell.

**(Answer)**

(b) [2 pts] Calculate  $\Delta G^\circ$  for the cell.

**(Answer)**

(c) [2 pts] Calculate the equilibrium constant for the cell.

**(Answer)**

(d) [4 pts] Suppose  $[\text{Pb}^{2+}] = 1.0 \times 10^{-2} \text{ M}$ ,  $[\text{VO}^{2+}] = 0.10 \text{ M}$ ,  $[\text{V}^{3+}] = 1.0 \times 10^{-5} \text{ M}$ , and the measured cell potential  $E = 0.640 \text{ V}$ . Calculate the pH of the solution in the cell.

**(Answer)**

## 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/periodic/>

GROUP	PERIOD																
1 IA	2 IIA	GROUP NUMBERS IUPAC RECOMMENDATION (1985)										GROUP NUMBERS CHEMICAL ABSTRACT SERVICE (1986)					
1	2	3	4	5	6	7	8	9	10	11	12	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1.0079	1.0079	ATOMIC NUMBER — 5 — 10.811 — RELATIVE ATOMIC MASS (1)															
H	He	SYMBOL — B —															
HYDROGEN	HELIUM	ELEMENT NAME															
3 6.941	4 9.0122	BORON — B —															
Li	Be	BORON															
11 22.990	12 24.305	ALUMINIUM															
Na	Mg	SILICON															
SODIUM	MAGNESIUM	PHOSPHORUS															
19 39.098	20 40.078	SULPHUR															
K	Ca	CHLORINE															
POTASSIUM	CALCIUM	ARGON															
37 85.468	38 87.62	KRYPTON															
Rb	Sr	BROMINE															
RUBIDIUM	STRONTIUM	SELENIUM															
55 132.91	56 137.33	GERMANIUM															
Cs	Ba	ARSENIC															
CAESIUM	BARIUM	TELLURIUM															
87 (223)	88 (226)	ANTIMONY															
Fr	Ra	TELURUM															
FRANCIUM	RADIUM	IODINE															
		XENON															
		RADON															

(1) Pure Appl. Chem., 73, No. 4, 867-893 (2001)

Relative atomic mass is shown with the significant figures. For elements with 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.

Editor: Aditya Varshani (aditya@netflix.com)

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	CERIUM	PRASEODYMIUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLIUM	ERBIUM	THULIUM	Ytterbium	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	CURCIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	Mendelevium	NOBELIUM	LAVRENCIUM		

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**Claim Form for General Chemistry Examination**

Class: \_\_\_\_\_, Professor Name: \_\_\_\_\_, 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	
Question #	Claims	Accepted? Yes(✓) or No(✓)	
		Yes: <input type="checkbox"/>	No: <input type="checkbox"/>
		Pts (+/-)	Reasons