

# 2021 Fall Semester Mid-term Examination For General Chemistry I

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

## NOTICE

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

Example:

Professor Name	Class	Student I.D. Number	Name

#1. (a).....

(b).....

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

**\*\* This paper consists of 14 sheets with 11 problems (page 13 - 14: Equation, constants & periodic table).** Please check all the page numbers before taking the exam. Please write down the unit of your answer when **applicable**. You will get 30% deduction for a value that is missing its unit.

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

(채점 답안지 분배 및 이의신청 일정)

### 1. Period, Location, and Procedure

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

### 2. Final Confirmation

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

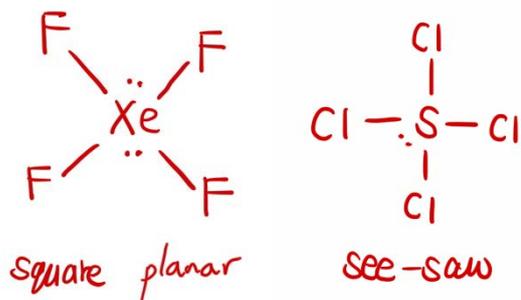
**\*\* For further information, please visit General Chemistry website at [www.gencheminkaist.pe.kr](http://www.gencheminkaist.pe.kr)**

**1. (total 8 pts)**

Methane ( $\text{CH}_4$ ), xenon tetrafluoride ( $\text{XeF}_4$ ), and sulfur tetrachloride ( $\text{SCl}_4$ ) all have molecular structures of the central atom bonded to four other atoms.

(a) Draw the Lewis diagrams of  $\text{CH}_4$ ,  $\text{XeF}_4$ , and  $\text{SCl}_4$ , and state their molecular geometries. (6 pts)

**(Answer)**



*CH<sub>4</sub>: diagram 1 pt, geometry 1 pt*

*XeF<sub>4</sub>: diagram 1 pt, geometry 1 pt*

*SCl<sub>4</sub>: diagram 1 pt, geometry 1 pt*

(b) Explain why these three molecules have different molecular geometries, although they all have a similar chemical formula of  $\text{AX}_4$ . (2 pts)

**(Answer)**

Though  $\text{CH}_4$ ,  $\text{XeF}_4$ , and  $\text{SCl}_4$  all have four bonding pairs, they have the different number of lone pairs, which give them different steric numbers.  $\text{CH}_4$  has 4 bonding pairs and 0 lone pair, and because all four bonding pairs repel one another with equal strength, four hydrogen atoms lie at equal distance from one another, giving  $\text{CH}_4$  the tetrahedral shape.  $\text{XeF}_4$  has 4 bonding pairs and 2 lone pairs. While lone pairs affect the arrangement of other electron pairs, they are ignored when determining the molecular geometry, and thus  $\text{XeF}_4$  has a molecular geometry of square planar. In a similar manner, because  $\text{SCl}_4$  has 4 bonding pairs and 1 lone pair and a lone pair is not included in determining a molecular geometry,  $\text{SCl}_4$  has a see-saw shape.        *full points for correct answer*

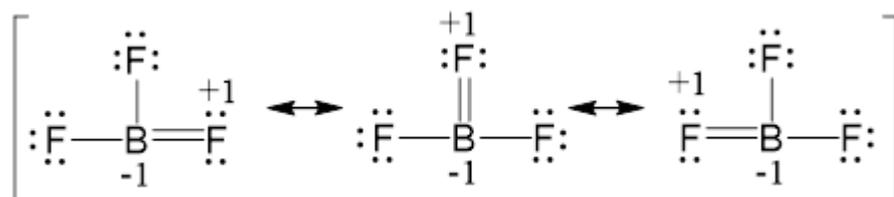
## 2. (total 10 pts)

Boron trifluoride,  $\text{BF}_3$ , is a highly reactive gas that condenses to a liquid at  $-100^\circ\text{C}$ .

(a) Draw the Lewis diagram of  $\text{BF}_3$  when this molecule follows the octet rule. Clearly mark the formal charges. (3 pts)

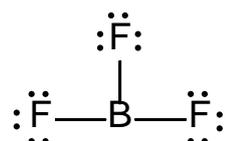
(Answer)

Lewis structure +1pt, resonance form +1pt, formal charge +1pt



(b) Experimental evidence strongly suggests there are no double bonds in  $\text{BF}_3$ . Draw the Lewis diagram if  $\text{BF}_3$  does not follow the octet rule. (2 pts)

(Answer)



(c) Explain the three dimensional structure of  $\text{BF}_3$  using the valence bond theory. (3 pts)

(Answer)  $sp^2$  hybrid +1 pt, trigonal planar +1 pt, reasonable explanation +1

In the lecture slide,

➤  $sp^2$ -hybridization  $\text{BF}_3$

Promotion:  $\text{B}: (1s)^2(2s)^2(2p_x)^1 \rightarrow \text{B}: (1s)^2(2s)^1(2p_x)^1(2p_y)^1$

Three equivalent  $sp^2$  hybrid orbitals:

$$\chi_1(r) = 2s + 2^{1/2}2p_y$$

$$\chi_2(r) = 2s + (3/2)^{1/2}2p_x - (1/2)^{1/2}2p_y$$

$$\chi_3(r) = 2s - (3/2)^{1/2}2p_x - (1/2)^{1/2}2p_y$$

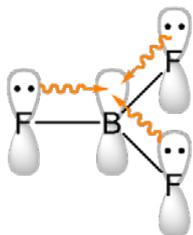
New electronic configuration,  $\text{B}: (1s)^2(\chi_1)^1(\chi_2)^1(\chi_3)^1$

Three bonds at an angle  $120^\circ$  in a plane  $\rightarrow$  trigonal planar

(d) Although there are only single bonds in  $\text{BF}_3$ , the length of the B-F bonds ( $1.30 \text{ \AA}$ ) is shorter than would be expected for common single bonds. What may lead to this shortness? (2 pts)

(Answer) Any reasonable descriptions, +2

This shortness may indicate stronger B-F pi-bonding (perpendicular to the molecular plane) in the fluoride, although there are no strict double bonds. The ionic nature of the bonds may also strengthen the B-F bond.



### 3. (total 10 pts)

The motion of an electron in a bond can be treated approximately as the motion in an one-dimensional box. Consider the electrons in O<sub>2</sub> and ozone (O<sub>3</sub>), and note that the lengths of the O-O and O=O bonds are 1.48 and 1.21 Å, respectively.

(a) Calculate the energy of an electron in each of its three lowest allowed states if it is confined to move in a one-dimensional box. (6 pts)

**(Answer)**

The allowed energies of a particle in an one-dimensional box are given by text equation 4.37

$$E_n = \frac{h^2 n^2}{8mL^2}$$

The particle in this case is an electron, so the value of m is known. The box length of O<sub>2</sub> is  $1.21 \times 10^{-10}$  m and that of ozone with the resonance structures of

$\text{O}=\text{O}^{\oplus}-\text{O}^{\ominus} \longleftrightarrow \text{O}^{\ominus}-\text{O}^{\oplus}=\text{O}$  is  $(1.21+1.48) \times 10^{-10}$  m. For n=1,2,3,

O<sub>2</sub>; E<sub>1</sub>=4.12\*10<sup>-18</sup> J, E<sub>2</sub>=16.5\*10<sup>-18</sup> J, E<sub>3</sub>=37.0\*10<sup>-18</sup> J

O<sub>3</sub>; E<sub>1</sub>=0.83\*10<sup>-18</sup> J, E<sub>2</sub>=3.33\*10<sup>-18</sup> J, E<sub>3</sub>=7.49\*10<sup>-18</sup> J

+1 pt for six Es

2 pt if rationale is correct

(b) Calculate the wavelength of light necessary to excite the electron from its ground state to the first excited state. (4 pts)

**(Answer)**

The wavelength of the photon required to excite the electron from n=1 to n=2 is

$$\lambda = \frac{hc}{E_2 - E_1}; \text{ for O}_2, 1.61 \times 10^{-8} \text{ m} = 16.1 \text{ nm} \text{ \& for O}_3, 7.95 \times 10^{-8} \text{ m} = 79.5 \text{ nm}.$$

+2 pt for each

**4. (total 6 pts)**

An electron falls from  $n=5$  state to  $n=3$  state and then to  $n=1$  state.

(a) Let's define  $\nu_1$  as the frequency of light emitted in transition from  $n=5$  state to  $n=3$  state,  $\nu_2$  as the frequency of light emitted in transition from  $n=3$  state to  $n=1$  state, and  $\nu_{\text{tot}}$  as the frequency of the light that would be emitted if it falls directly from  $n=5$  to  $n=1$  state. Find the relation between  $\nu_1$ ,  $\nu_2$ , and  $\nu_{\text{tot}}$ .

(3 pts)

**(Answer)**

The total energy emitted is equal to the sum of the energy emitted at the two transitions. This implies

$$h\nu_{\text{tot}} = h\nu_1 + h\nu_2$$

dividing by  $h$  gives  $\nu_{\text{tot}} = \nu_1 + \nu_2$

(b) Find the relation between the respective wavelengths,  $\lambda_1$ ,  $\lambda_2$ , and  $\lambda_{\text{tot}}$ . (3 pts)

**(Answer)**

to find the relation between the wavelengths we substitute frequencies by the  $c/\lambda$ . I.E

$$c/\lambda_{\text{tot}} = c/\lambda_1 + c/\lambda_2$$

Dividing by  $c$  gives

$1/\lambda_{\text{tot}} = 1/\lambda_1 + 1/\lambda_2$  rearranging gives

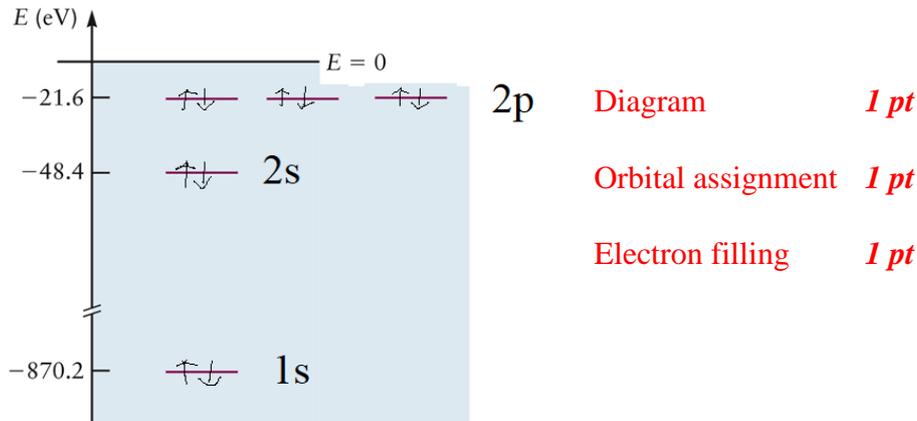
$$\lambda_{\text{tot}} = \lambda_1 \lambda_2 / (\lambda_1 + \lambda_2)$$

**5. (total 10 pts)**

By photoelectron spectroscopy, three ionization energies were identified for electrons in Ne: 870.2, 48.4, and 21.6 eV. Answer the following questions.

(a) Draw an energy-level diagram for Ne, assign atomic orbitals for each energy level, and fill up the electrons in the orbitals. (3 pt)

**(Answer)**



(b) Based on the Bohr theory, calculate the energy level of the lowest orbital for Ne: (2 pt)

$$E_n = -2.18 \times 10^{-18} \text{ J } (Z^2/n^2)$$

**(Answer)**

As  $Z = 10$  and  $n = 1$ ,  $E_1 = -2.18 \times 10^{-16} \text{ J}$  2 pts

(c) Estimate the effective Z ( $Z_{\text{eff}}$ ) that can match the Bohr theory with the experimental observation. (3 pt)

**(Answer)**

The experimentally determined  $E_{1s} = -870.2 \text{ eV} \times 1.60 \times 10^{-19} \text{ J/eV} = -1.39 \times 10^{-16} \text{ J}$

$$(Z_{\text{eff}})^2 = -1.39 \times 10^{-16} \text{ J} / -2.18 \times 10^{-16} \text{ J} \times 1^2, Z_{\text{eff}} = 8.00 \quad 3 \text{ pts}$$

(d) Suppose Ne is excited by X-ray with energy of 1000 eV. Calculate the velocity of photoelectron that was originally in the lowest orbital. (2 pt)

**(Answer)** As  $870.2 \text{ eV} = 1000 \text{ eV} - 1/2 m_e v_e^2$ ,  $v_e = 6.76 \times 10^6 \text{ m/s}$  2 pts

**6. (total 6 pts)**

Calculate the average distance ( $\text{\AA}$ ) of an electron from the nucleus in the

- a) 1s orbital in a H atom
- b) 2s orbital in a  $\text{He}^+$  atom
- c) 2p orbital in a  $\text{Be}^{3+}$  atom

**(Answer)**

a) H atom

$$\bar{r}_{nl} = \frac{n^2 a_0}{Z} \left\{ 1 + \frac{1}{2} \left[ 1 - \frac{l(l+1)}{n^2} \right] \right\}$$

$$\bar{r}_{10} = \frac{1^2 a_0}{1} \left\{ 1 + \frac{1}{2} \left[ 1 - \frac{0(0+1)}{1^2} \right] \right\}$$

$$\bar{r}_{10} = \frac{3}{2} a_0 = 0.7935 \text{ \AA}$$

b)  $\text{He}^+$  atom

$$\bar{r}_{20} = \frac{2^2 a_0}{2} \left\{ 1 + \frac{1}{2} \left[ 1 - \frac{0(0+1)}{2^2} \right] \right\}$$

$$\bar{r}_{20} = 3a_0 = 1.587 \text{ \AA}$$

c)  $\text{Be}^{3+}$  atom

$$\bar{r}_{21} = \frac{2^2 a_0}{4} \left\{ 1 + \frac{1}{2} \left[ 1 - \frac{1(1+1)}{2^2} \right] \right\}$$

$$\bar{r}_{21} = \frac{5}{4} a_0 = 0.66125 \text{ \AA}$$

*2 pts each*

**7. (total 10 pts)**

If an electron is removed from a fluorine molecule, an  $F_2^+$  molecular ion forms.

(a) Give the molecular electron configurations for  $F_2$  and  $F_2^+$ . (3 pt)

**(Answer)**

$F_2$  is a homonuclear diatomic molecule, which has 18 electrons of which 14 are valence electrons. The  $F_2^+$  ion has lost a valence electron and so has 13. Based on the correlation diagram for  $F_2$ , the energetic order can be obtained like the following.



(b) Give the bond order of each species. (2 pts)

**(Answer)**

The  $F_2$  molecule has two more bonding than antibonding electrons. Its order is 1;  $F_2^+$  ion has three more bonding than antibonding electrons. Its bonding order is  $3/2$ .

(c) Predict which species should be paramagnetic. (2 pt)

**(Answer)**

The  $F_2$  molecule has zero unpaired electrons. Accordingly,  $F_2$  is diamagnetic. The  $F_2^+$  ion has an odd number of electrons. Because at least one electron (a  $\pi_{g2p}^*$  electron) is unpaired. So,  $F_2^+$  ion is paramagnetic.

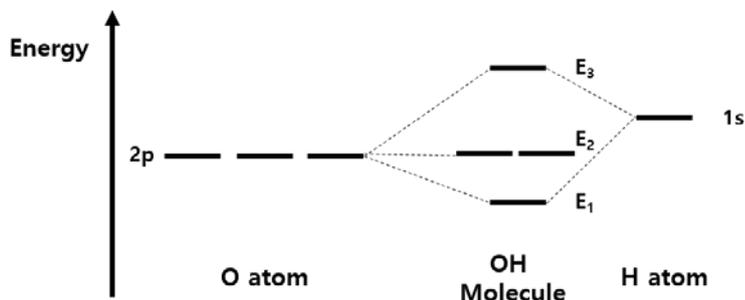
(d) Predict which species has the greater bond dissociation energy. (3 pts)

**(Answer)**

The  $F_2^+$  ion has a larger bond order and therefore requires more energy to dissociate than  $F_2$  ion's case.

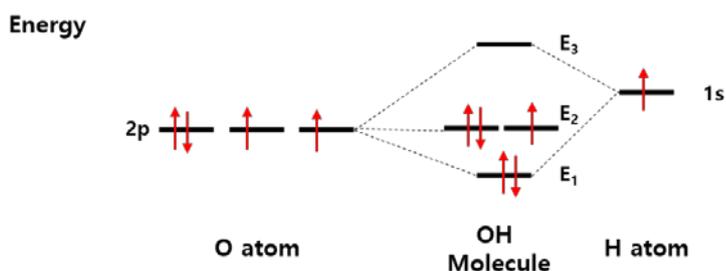
### 8. (total 10 pts)

The figure below shows the energy levels of OH molecular orbitals obtained by combining O and H atomic orbitals. (Note:  $E_2$  orbitals are obtained only from O atomic orbitals and called non-bonding molecular orbitals.)



(a) Properly draw the ground state electron configuration. Fill up the electrons of atomic orbitals, too. (3 pts)

**(Answer)**



(b) Is the first ionization energy of OH less than that of H? Please explain the reason for your answer. (2 pts)

**(Answer)**

No. Because the electrons in the HOMO of OH have a lower energy level than the 1s electrons of H, and thus have higher ionization energy.

(c) What is the bond order of the ground state OH? (2 pts)

**(Answer)**

Bond order =  $(1/2) \times (\text{number of electrons in bonding MOs} - \text{number of electrons in antibonding MOs}) = 2/2 = 1$

(d) Why do we call OH a “radical”? How does the MO diagram support this? (2 pts)

**(Answer)**

It has an unpaired electron in a non-bonding orbital.

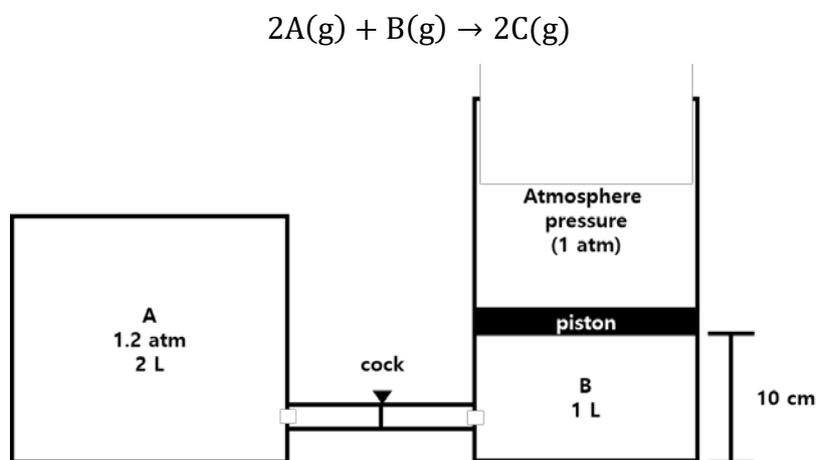
(e) Is there a nodal plane between H and O in the molecular orbital corresponding to  $E_3$ ? (1 pts)

**(Answer)**

Yes.

**9. (total 10 pts)**

The following is a device that connects two containers containing gas A and gas B with a cock. Gas A reacts with gas B to form gas C. The cock was opened and equilibrium was reached. (The temperature is constant, all gases behave ideally, and the reaction proceeded completely. Ignore the volume of the connection between two containers.)



(a) How many centimeters did the piston move? Write the length and direction of piston movement. (5 pts)

**(Answer)**



Before reaction  $1.2\text{atm} \cdot 2\text{L}$   $1\text{atm} \cdot 1\text{L}$

After reaction  $-2\text{atm} \cdot \text{L}$   $-1\text{atm} \cdot \text{L}$   $+2\text{atm} \cdot \text{L}$

$0.4\text{atm} \cdot \text{L}$   $2\text{atm} \cdot \text{L}$

Total:  $2.4 \text{ atm} \cdot \text{L}$

Pressure of inside and outside of the piston is same as 1 atm.

So, total volume is 2.4 L. The piston should come down 6 cm to meet the volume.

Answer) 6 cm, down

*Fine with different methods*

(b) What is the mole fraction of each gas? (3 pts)

**(Answer)**

A:  $1/6$ , B: 0, C:  $5/6$

(c) The ratio of the molecular weights of gas A and B is 1:2. Find the ratio of the diffusion rates of A and C. (2 pts)

**(Answer)**

$$M_C = (2M_A + M_B)/2, M_A:M_B:M_C = 1:2:2, \frac{V_A}{V_C} = \sqrt{\frac{M_C}{M_A}} = \sqrt{2}, V_A = \sqrt{2}V_C$$

**10. (total 10 pts)**

	Formula	Name	M.W.	a (bar•L <sup>2</sup> /mol <sup>2</sup> )	b (L/mol)
(a)	C <sub>2</sub> H <sub>5</sub> F	Fluoroethane	48.06	8.17	0.07758
(b)	CH <sub>3</sub> SH	Methanethiol	48.11	8.911	0.06756
(c)	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	Methyl formate	60.05	11.54	0.08442
(d)	CH <sub>3</sub> COOH	Acetic acid	60.05	17.71	0.1065
(e)	C <sub>2</sub> F <sub>4</sub>	Tetrafluoroethylene	100.02	6.954	0.08085
(f)	C <sub>2</sub> H <sub>5</sub> Br	Bromoethane	108.96	11.89	0.08406

For molecules (a)~(f), the chemical formula, the molecular weight, and the van der Waals constants a's and b's are given in the above table. Which of the following is correct in predicting boiling points in an increasing order? Choose an answer and give an explanation.

- ① a < b < c < d < e < f
- ② e < a < b < c < f < d
- ③ b < a < e < f < c < d
- ④ a < b < c < e < f < d
- ⑤ d < f < c < b < a < e

**(Answer)**

② e < a < b < c < f < d is correct. **+5 pts**

From the van der Waals equation, the vapor pressure of real gases can be predicted. A higher “a” value indicates greater attractive interactions between molecules and thus smaller vapor pressure. Then more thermal energy is required for reaching 1 atm, i.e., boiling.

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

$$P = \frac{RT}{\frac{V}{n} - b} - a\left(\frac{n}{V}\right)^2$$

**+5 pts**

**11. (total 10 pts)**

The boiling point of HF, HCl, HBr and HI are 293K, 189K, 206K and 238K, respectively.

(a) Which type of intermolecular forces are present in the molecules HF, HCl, HBr, and HI? (4 pts)

**(Answer)**

HCl, HBr and HI: dipole-dipole and London forces

HF: hydrogen bonding, dipole-dipole, and London forces

(b) Looking at the trend of boiling points of HCl, HBr and HI, which intermolecular force is predominant among these molecules? (4 pts)

**(Answer)**

Electronegativity decreases from Cl to I, so the dipole moment decreases from HCl to HI. As the boiling point is increasing from HCl to HI, it means London forces are predominant.

London force is directly proportional to the number of electrons in a molecule.

(c) Why is the boiling point of HF the highest? (2 pts)

**(Answer)**

F has the highest electronegativity. As a result, HF has the highest dipole moment and also has hydrogen bonding. Therefore, HF shows the highest boiling point.

## Physical Constants

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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	$R = 8.314472 \text{ J mol}^{-1} \text{ K}^{-1}$ $= 0.0820574 \text{ L atm mol}^{-1} \text{ K}^{-1}$

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

## Conversion factors

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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	$1 \text{ torr} = 133.3224 \text{ Pa}$

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# 2021 Fall Semester Final Examination For General Chemistry I

Date: Dec 15 (Wed), Time Limit: 19:00 ~ 22:00

## NOTICE

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Example:

Professor Name	Class	Student I.D. Number	Name

#1. (a).....

(b).....

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**1. (total 10 pts)**

A mixture of 1.78 kg of water and 262 g of ice at 0°C is in a reversible process, brought to a final equilibrium state where the water-to-ice mass ratio is 1:1 at 0°C. ( $\Delta H_{\text{fus}}(\text{H}_2\text{O}) = 6.007 \text{ kJ/mol}$ , Molar mass of  $\text{H}_2\text{O}$ : 18.02 g/mol)

(a) Calculate the entropy change of the system during this process.

**(Answer) (5 pts)**

$$\text{Mass of ice-water mixture} = (\text{Mass of water}) + (\text{Mass of ice}) = (1.78 \text{ kg}) + (0.262 \text{ kg}) = 2.04 \text{ kg}$$

If eventually the ice and water have the same mass, then the final state will have 1.02 kg (2.04 kg/2) of each.

The mass of the water that changed into ice,  $\Delta m$ , will be the difference of initial mass of water  $m_i$  and final mass of water  $m_f$ .

$$\Delta m = m_i - m_f = 1.78 \text{ kg} - 1.02 \text{ kg} = 0.76 \text{ kg}$$

$$760 \text{ g} / 18.02 \text{ g/mol} = 42.18 \text{ mol}$$

The change in entropy at 0°C

$$\Delta S = \frac{n\Delta H_{\text{freez}}}{T} = -\frac{n\Delta H_{\text{fus}}}{T} = -\frac{(42.18 \text{ mol})(6007 \text{ J mol}^{-1})}{273.15 \text{ K}} = -927.6 \text{ J K}^{-1}$$

(b) The system is then returned to the first equilibrium state, but in an irreversible way. The system is heated by using a Bunsen burner. Heat of  $3.04 \times 10^5 \text{ J}$  is used. Calculate the entropy change of the system during this process with proper explanation.

**(Answer) (5 pts)**

The entropy  $S$  of a system is a state function and depends only on the state of the system and not how it reached that condition.

Now the system is returned to the first equilibrium state, but in an irreversible way. Thus, the change in entropy  $\Delta S$  of the system during this process is equal to the negative of previous case.

$$\text{So, } \Delta S = -(-927.6 \text{ J/K}) = 927.6 \text{ J/K}$$

## 2. (total 10 pts)

Over what range of temperature is each of the following processes spontaneous? Assume that all gases are at a pressure of 1 atm. Use the following table, and assume that the enthalpies and entropies are independent upon the temperature.

Substance	$\Delta H_f^\circ$ (kJ mol <sup>-1</sup> )	$S^\circ$ (J K <sup>-1</sup> mol <sup>-1</sup> )	Substance	$\Delta H_f^\circ$ (kJ mol <sup>-1</sup> )	$S^\circ$ (J K <sup>-1</sup> mol <sup>-1</sup> )
Fe(s)		27.28	CO(g)	-110.52	197.56
FeO(s)	-266.27	57.49	COCl <sub>2</sub> (g)	-218.8	283.53
Fe <sub>2</sub> O <sub>3</sub> (s)	-824.2	87.40	O <sub>2</sub> (g)		205.03
C(s)		5.74	Cl <sub>2</sub> (g)		222.96

(a) The rusting of iron, a complex reaction that can be approximated as



**(Answer)**

$$\Delta H_f^\circ = 2 \times (-824.2) = -1648.4 \text{ kJ mol}^{-1}$$

$$\Delta S^\circ = 2 \times (87.40) - 4 \times (27.28) - 3 \times (205.03) = -549.41 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$T = \Delta H_f^\circ / \Delta S^\circ = -1648.4 \times 10^3 / -549.41 = 3000 \text{ K}$$

**+3 pts**

The reaction is spontaneous **below 3000 K.**

**below, +1 pt**

(b) The preparation of the poisonous gas phosgene:  $\text{CO}(g) + \text{Cl}_2(g) \rightarrow \text{COCl}_2(g)$

**(Answer)**

$$\Delta H_f^\circ = (-218.8) - (-110.52) = -108.3 \text{ kJ mol}^{-1}$$

$$\Delta S^\circ = (283.53) - (222.96) - (197.56) = -136.99 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$T = \Delta H_f^\circ / \Delta S^\circ = -108.3 \times 10^3 / -136.99 = 790 \text{ K}$$

**+2 pts**

The reaction is spontaneous **below 790 K.**

**below, +1 pt**

(c) The reduction of iron(II) oxide (wüstite) by coke (carbon), a step in the production of iron in a blast furnace:  $\text{FeO}(s) + \text{C}(s, \text{gr}) \rightarrow \text{Fe}(s) + \text{CO}(g)$

**(Answer)**

$$\Delta H_f^\circ = (-110.52) - (-266.27) = 155.75 \text{ kJ mol}^{-1}$$

$$\Delta S^\circ = (27.28) + (197.56) - (57.49) - (5.74) = 161.61 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$T = \Delta H_f^\circ / \Delta S^\circ = 155.75 \times 10^3 / 161.61 = 960 \text{ K}$$

**+2 pts**

The reaction is spontaneous **above 960 K.**

**above, +1 pt**

### 3. (total 10 pts)

A student claims that the process of recycling aluminum (initially at 298.15 K) by melting the metal to remove impurities requires less energy than the process of extracting Al from  $\text{Al}_2\text{O}_3$  as expressed in the following equation:  $\text{Al}_2\text{O}_3(s) \rightarrow 2 \text{Al}(s) + \frac{3}{2} \text{O}_2(g)$ . The melting point of Al is 933.47 K, the molar heat capacity of Al is  $24.20 \text{ J mol}^{-1} \text{ K}^{-1}$ , and the enthalpy of fusion of Al is  $10.71 \text{ kJ mol}^{-1}$ . The standard enthalpy of formation of  $\text{Al}_2\text{O}_3$  is  $-1675.7 \text{ kJ mol}^{-1}$ . Calculate the required energies of each process and determine if the student's claim is true.

#### Recycling (Melting): (4 pts)

$n$ : moles of Al,  $c_m$ : molar heat capacity of Al,  $\Delta H_{\text{fus}}^\circ$ : enthalpy of fusion of Al,  $T$ : temperature

The heat required for the process of melting the Al is the sum of the heat required to raise the temperature to the melting point of 933.47 K from 298.15 K and the heat required to melt the Al.

$$\begin{aligned} & nc_m\Delta T + n\Delta H_{\text{fus}}^\circ \\ = & n(24.20 \text{ J mol}^{-1} \text{ K}^{-1})(933.47 \text{ K} - 298.15 \text{ K}) + n(10.71 \times 10^3 \text{ J mol}^{-1}) \\ = & (2.608 \times 10^4 \text{ J mol}^{-1})n \end{aligned}$$

Thus,  $2.608 \times 10^4 \text{ J}$  required per mole of Al.

#### Extracting: (4 pts)

The given reaction of extracting Al from  $\text{Al}_2\text{O}_3$  is the reverse of the reaction of formation of  $\text{Al}_2\text{O}_3$ . Therefore, the standard enthalpy of reaction for the reaction of extracting Al from  $\text{Al}_2\text{O}_3$  is  $1675.7 \text{ kJ mol}^{-1}$ .

$$1675.7 \times 10^3 \text{ J mol}^{-1} \times \frac{1 \text{ mol rxn}}{2 \text{ mol Al}} \times n = (8.3785 \times 10^5 \text{ J mol}^{-1})n$$

Thus,  $8.3785 \times 10^5 \text{ J}$  required per mole of Al.

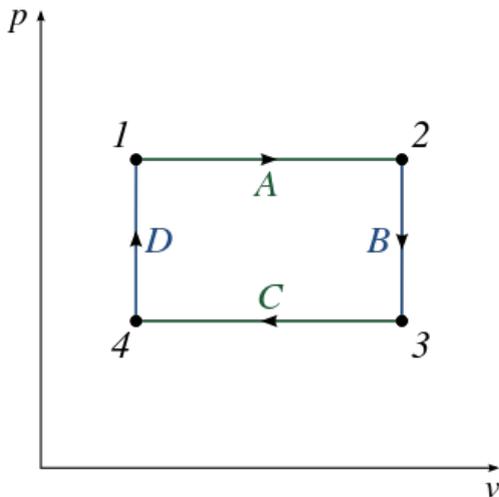
$$8.3785 \times 10^5 \text{ J mol}^{-1} > 2.608 \times 10^4 \text{ J mol}^{-1}$$

(2 pts)  $\therefore$  TRUE

**4. (total 12 pts)**

The following cycle consists of two isobaric and two isochoric processes. The cycle starts at point 1 where  $P_1 = 2 \text{ atm}$ ,  $V_1 = 20 \text{ L}$ . The volume at point 2 is then  $60 \text{ L}$  and the pressure at point 3 is  $1 \text{ atm}$ . The cycle works with  $1 \text{ mole}$  of monoatomic gas.

- Calculate the work done on the gas during the  $1 \rightarrow 2$ ,  $2 \rightarrow 3$ ,  $3 \rightarrow 4$ , and  $4 \rightarrow 1$  process in joules.
- Calculate the total work done by one cycle in joules.
- At what point does the gas reach a maximum temperature and what is that temperature?
- Calculate the entropy change of the system when the gas goes from state 1 to state 3.



A) Process 1-2 is an isobaric process.  $W = -P\Delta V = -40\text{L} * 2 \text{ atm} = -80\text{atm}\cdot\text{L} = - 8.106 \text{ kJ}$ . Process 2-3 is an isochoric process  $\Rightarrow$  no work. Process 3-4 is an isobaric process.  $W = -P\Delta V = +40\text{L} * 1 \text{ atm} = 40\text{atm}\cdot\text{L} = + 4.053 \text{ kJ}$ . Process 4-1 is an isochoric process  $\Rightarrow$  no work. **(4 pts; 1pt each)**

B) Total Work:  $= W_{12} + W_{23} + W_{34} + W_{41} = -4.053 \text{ kJ}$  **(2pt)**

C) At 1:  $T_1 = P_1 * V_1 / (n * R) = 487.4 \text{ K}$  At 2:  $T_2 = P_2 * V_2 / (n * R) = 1462.4 \text{ K}$ . At 3:  $T_3 = P_3 * V_3 / (n * R) = 731.2 \text{ K}$ . At 4:  $T_4 = P_4 * V_4 / (n * R) = 243.7 \text{ K}$ . So we reach a maximum temperature at point 2 with  $1462.4 \text{ K}$ . **(3 pts)**

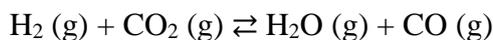
D) We can either choose Path 1-2-3 or Path 1-4-3, since entropy is a function of state. For 1-2-3:

$$\begin{aligned} \Delta S &= \int_{T_1}^{T_2} \frac{c_p}{T} dT + \int_{T_2}^{T_3} \frac{c_v}{T} dT = c_p \times \ln \frac{T_2}{T_1} + c_v \ln \frac{T_3}{T_2} = \frac{5R}{2} \times \ln \frac{T_2}{T_1} + \frac{3R}{2} \times \ln \frac{T_3}{T_2} \\ &= R \left[ \frac{5}{2} \times 1.0986 + \frac{3}{2} \times (-0.6931) \right] = R \times 1.706 = 14.2 \text{ J K}^{-1} \end{aligned}$$

**(3 pts)**

### 5. (total 10 pts)

The water–gas shift reaction is important in several chemical processes, such as the production of H<sub>2</sub> for fuel cells. This reaction can be written as follows:



The equilibrium constant  $K = 0.106$  at 700 K. If a mixture of gases that initially contains 0.0150 M H<sub>2</sub> and 0.0150 M CO<sub>2</sub> is allowed to equilibrate at 700 K, what are the final concentrations of all substances present?

**(Answer)**

Reaction	H <sub>2</sub> (g)	+	CO <sub>2</sub> (g)	⇌	H <sub>2</sub> O (g)	+	CO (g)
Initial	0.0150		0.0150		0		0
Change	- x		- x		+ x		+ x
Equilibrium	0.0150 - x		0.0150 - x		x		x

We can now use the equilibrium equation and the given  $K$  to solve for  $x$ :

$$K = \frac{[\text{H}_2\text{O}][\text{CO}]}{[\text{H}_2][\text{CO}_2]} = \frac{(x)(x)}{(0.0150 - x)(0.0150 - x)} = \frac{x^2}{(0.0150 - x)^2} = 0.106$$
$$\frac{x^2}{(0.0150 - x)^2} = 0.106$$
$$\frac{x}{(0.0150 - x)} = 0.106^{0.5} = 0.326$$

$$x = 0.00369 \text{ M} \quad (2 \text{ pts})$$

The equilibrium concentrations of all species in the reaction mixture are as follows:

$$[\text{H}_2]_e = (0.0150 - x) = (0.0150 - 0.00369) = 0.0113 \text{ M} \quad (2 \text{ pts})$$

$$[\text{CO}_2]_e = (0.0150 - x) = (0.0150 - 0.00369) = 0.0113 \text{ M} \quad (2 \text{ pts})$$

$$[\text{H}_2\text{O}]_e = x = 0.00369 \text{ M} \quad (2 \text{ pts})$$

$$[\text{CO}]_e = x = 0.00369 \text{ M} \quad (2 \text{ pts})$$

We can check our work by inserting the calculated values back into the equilibrium constant expression:

$$K = \frac{[\text{H}_2\text{O}][\text{CO}]}{[\text{H}_2][\text{CO}_2]} = \frac{(0.00369)^2}{(0.0113)^2} = 0.107$$

**6. (total 6 pts)**

Consider a weak acid, HA, with  $pK_a = 5.20$ . You start with 100.0 mL of a buffer solution in which  $[A^-] = 0.40$  M and  $[HA] = 0.60$  M. You add 100 mL of 0.10 M NaOH solution. What is the change in pH caused by addition of NaOH?

**(Answer)**

Initial pH:

$$pH = pK_a - \log_{10} \left( \frac{[HA]}{[A^-]} \right) = 5.2 - \log_{10} \left( \frac{0.60}{0.40} \right) = 5.02$$

**(3 pts)**

When  $OH^-$  is added:

$[HA] \rightarrow 0.30$  M,  $[OH^-] \rightarrow 0.05$  M,  $[A^-] \rightarrow 0.20$  M

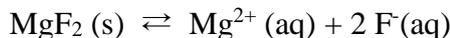
Reaction	$HA(aq) + OH^-(aq) \rightleftharpoons A^-(aq) + H_2O(l)$			
Initial	0.30	0.050	0.20	
Change	- 0.050	- 0.050	+ 0.050	
Equilibrium	0.25	0	0.25	

$$pH = pK_a - \log_{10} \left( \frac{[HA]}{[A^-]} \right) = 5.2 - \log_{10} \left( \frac{0.25}{0.25} \right) = 5.20$$

Change in pH = + 0.18 **(3 pts)**

**7. (total 10 pts)**

In a saturated solution of  $\text{MgF}_2$  at  $18^\circ\text{C}$ , the concentration of  $\text{Mg}^{2+}$  is  $1.21 \times 10^{-3} \text{ M}$ . The equilibrium is represented by the equation below.



(a) Write the expression for the solubility product constant,  $K_{\text{sp}}$ , and calculate its value at  $18^\circ\text{C}$ .

**(Answer) (4 pts)**

$$K_{\text{sp}} = [\text{Mg}^{2+}] [\text{F}^{-}]^2$$

$$[\text{Mg}^{2+}] = 1.21 \times 10^{-3} \text{ M}$$

$$[\text{F}^{-}] = 2 \times 1.21 \times 10^{-3} = 2.42 \times 10^{-3} \text{ M}$$

$$K_{\text{sp}} = (1.21 \times 10^{-3})(2.42 \times 10^{-3})^2 = 7.09 \times 10^{-9}$$

(b) Calculate the equilibrium concentration of  $\text{Mg}^{2+}$  in 1.00 liter of saturated  $\text{MgF}_2$  solution at  $18^\circ\text{C}$  to which 0.100 mole of solid KF has been added. The KF dissolves completely. Assume the volume change is negligible.

$$[\text{F}^{-}] = \frac{0.100 \text{ mol}}{1.00 \text{ L}} = 0.100 \text{ M}$$

Compared to this value, initial concentrations of  $\text{Mg}^{2+}$  and  $\text{F}^{-}$  are negligible and can be set to 0.

Reaction	$\text{MgF}_2 (\text{s})$	$\rightleftharpoons$	$\text{Mg}^{2+} (\text{aq})$	+	$2 \text{F}^{-} (\text{aq})$
Initial			0		0.100
Change			+x		+2x
Equilibrium			x		0.100 + 2x

$$K_{\text{sp}} = [\text{Mg}^{2+}][\text{F}^{-}]^2$$

$$7.09 \times 10^{-9} = (x)(0.100 + 2x)^2$$

$$7.09 \times 10^{-9} = (x)(0.100)^2 \text{ since } 2x \text{ is negligibly small.}$$

$$x = 7.09 \times 10^{-7} \text{ M} = [\text{Mg}^{2+}] \quad \text{(3 pts)}$$

(c) Predict whether a precipitate of  $\text{MgF}_2$  will form when 100.0 mL of a  $3.00 \times 10^{-3} \text{ M}$   $\text{Mg}(\text{NO}_3)_2$  solution is mixed with 200.0 mL of a  $2.00 \times 10^{-3} \text{ M}$  NaF solution at  $18^\circ\text{C}$ .

**(Answer) (3 pts)**

$$\text{Total solution volume} = 100.0 \text{ mL} + 200.0 \text{ mL} = 300.0 \text{ mL} = 0.300 \text{ L}$$

$$[\text{Mg}^{2+}] = (3.00 \times 10^{-3} \text{ M})(0.100 \text{ L}) / (0.300 \text{ L}) = 1.00 \times 10^{-3} \text{ M}$$

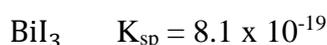
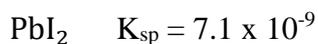
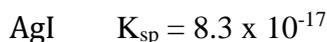
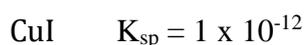
$$[\text{F}^{-}] = (2.00 \times 10^{-3} \text{ M})(0.200 \text{ L}) / (0.300 \text{ L}) = 1.33 \times 10^{-3} \text{ M}$$

$$Q = [\text{Mg}^{2+}][\text{F}^{-}]^2 = (1 \times 10^{-3})(1.33 \times 10^{-3})^2 = 1.78 \times 10^{-9} < K_{\text{sp}} = 7.09 \times 10^{-9}$$

Since  $Q < K_{\text{sp}}$ , a precipitate of  $\text{MgF}_2$  will not be formed.

### 8. (total 12 pts)

The solubility products for a series of iodides are



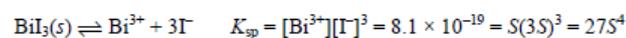
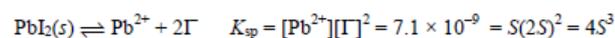
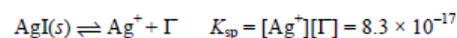
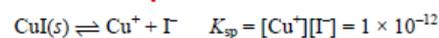
List these four compounds in order of decreasing molar solubility in

(a) water.

(b) 0.20 M NaI.

(c) 0.020 M solution of the solute cation.

**Answer) (4 pts each)**



(a) For CuI,  $S = [\text{Cu}^+] = [\text{I}^-] = \sqrt{1 \times 10^{-12}} = 1 \times 10^{-6} \text{ M}$

For AgI,  $S = [\text{Ag}^+] = [\text{I}^-] = \sqrt{8.3 \times 10^{-17}} = 9.1 \times 10^{-9} \text{ M}$

For  $\text{PbI}_2$ ,  $S = \sqrt[3]{\frac{7.1 \times 10^{-9}}{4}} = 1.2 \times 10^{-3} \text{ M}$

For  $\text{BiI}_3$ ,  $S = \sqrt[4]{\frac{8.1 \times 10^{-19}}{27}} = 1.3 \times 10^{-5} \text{ M}$

So, solubilities are in the order  $\text{PbI}_2 > \text{BiI}_3 > \text{CuI} > \text{AgI}$

(b) For CuI,  $S = 1 \times 10^{-12}/0.20 = 5 \times 10^{-12} \text{ M}$

For AgI,  $S = 8.3 \times 10^{-17}/0.20 = 4.2 \times 10^{-16} \text{ M}$

For  $\text{PbI}_2$ ,  $S = 7.1 \times 10^{-9}/(0.20)^2 = 1.8 \times 10^{-7} \text{ M}$

For  $\text{BiI}_3$ ,  $S = 8.1 \times 10^{-19}/(0.20)^3 = 1.0 \times 10^{-16} \text{ M}$

So, solubilities are in the order  $\text{PbI}_2 > \text{CuI} > \text{AgI} > \text{BiI}_3$

(c) For CuI,  $S = 1 \times 10^{-12}/0.020 = 5 \times 10^{-11} \text{ M}$

For AgI,  $S = 8.3 \times 10^{-17}/0.020 = 4.2 \times 10^{-15} \text{ M}$

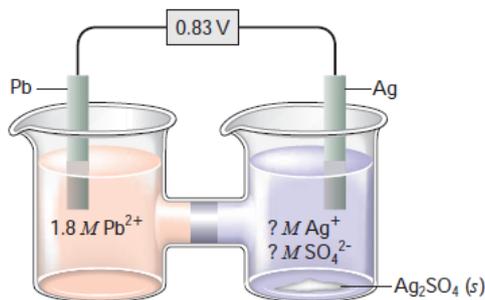
For  $\text{PbI}_2$ ,  $S = \frac{1}{2} \sqrt{\frac{7.1 \times 10^{-9}}{0.020}} = 3.0 \times 10^{-4} \text{ M}$

For  $\text{BiI}_3$ ,  $S = \frac{1}{3} \sqrt[3]{\frac{8.1 \times 10^{-19}}{0.020}} = 1.1 \times 10^{-6} \text{ M}$

So solubilities are in the order,  $\text{PbI}_2 > \text{BiI}_3 > \text{CuI} > \text{AgI}$

**9. (total 10 pts)**

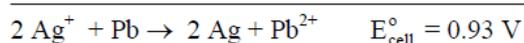
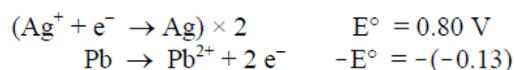
Consider the following galvanic cell:



$\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$	$E^\circ = 0.80\text{V}$
$\text{Pb}^{2+} + 2\text{e}^- \rightarrow \text{Pb}$	$E^\circ = -0.13\text{V}$

Calculate the  $K_{\text{sp}}$  value for  $\text{Ag}_2\text{SO}_4(\text{s})$ . To obtain silver ions in the right compartment (the cathode compartment), excess solid  $\text{Ag}_2\text{SO}_4$  was added and some of the salt dissolved.

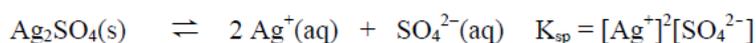
(Answer)



$$E = E^\circ - \frac{0.0591}{n} \log \frac{[\text{Pb}^{2+}]}{[\text{Ag}^+]^2}, \quad 0.83\text{V} = 0.93\text{V} - \frac{0.0591}{n} \log \frac{(1.8)}{[\text{Ag}^+]^2}$$

$$\log \frac{(1.8)}{[\text{Ag}^+]^2} = \frac{0.10(2)}{0.0591} = 3.4, \quad \frac{(1.8)}{[\text{Ag}^+]^2} = 10^{3.4}, \quad [\text{Ag}^+] = 0.027\text{M}$$

(6 pts)



Initial	$s = \text{solubility (mol/L)}$	0	0
Equil.		$2s$	$s$

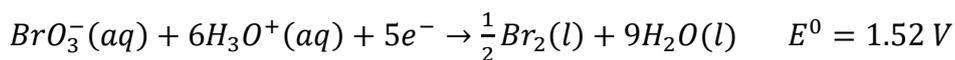
From problem:  $2s = 0.027\text{M}$ ,  $s = 0.027/2$

$$K_{\text{sp}} = (2s)^2(s) = (0.027)^2(0.027/2) = 9.8 \times 10^{-6}$$

(4 pts)

**10. (total 10 pts)**

The following reduction potentials are measured at pH 0:

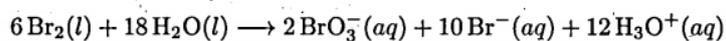


(a) Will bromine ( $\text{Br}_2(\text{l})$ ) disproportionate to  $\text{BrO}_3^-(\text{aq})$  and  $\text{Br}^-(\text{aq})$  spontaneously in acidic solution? & why?

(b) Which is the stronger reducing agent at pH 0:  $\text{Br}_2(\text{l})$  or  $\text{Br}^-$ ? & why?

Answer:

**17.25** a) The disproportionation of  $\text{Br}_2(\text{l})$  in acid is represented



for which the standard potential difference is

$$\begin{aligned} \mathcal{E}_{\text{cell}}^{\circ} &= \mathcal{E}_{\text{reduction}}^{\circ} - \mathcal{E}_{\text{oxidation}}^{\circ} \\ &= \mathcal{E}^{\circ}(\text{Br}_2|\text{Br}^-) - \mathcal{E}^{\circ}(\text{BrO}_3^-|\text{Br}_2) = 1.065 - 1.52 = -0.46 \text{ V} \end{aligned}$$

The negative  $\mathcal{E}_{\text{cell}}^{\circ}$  means  $\text{Br}_2(\text{l})$  will not disproportionate to  $\text{Br}^-(\text{aq})$  and  $\text{BrO}_3^-(\text{aq})$  in water under standard acidic conditions.

b) The reduction giving  $\text{Br}_2$  has a larger reduction potential than the one giving  $\text{Br}^-$  ion. Hence  $\text{Br}^-$  is more easily oxidized than  $\text{Br}_2$  and must be a stronger reducing agent under standard acidic conditions

**(a)  $E_{\text{cell}}$  calculation: 3 pts; phrase 'no disproportionation': 2pts**

**(b) Answer: 3pts, reason: 2pts**

## Physical Constants

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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	$R = 8.314472 \text{ J mol}^{-1} \text{ K}^{-1}$ $= 0.0820574 \text{ L atm mol}^{-1} \text{ K}^{-1}$

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

## Conversion factors

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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	$1 \text{ torr} = 133.3224 \text{ Pa}$

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