

2021 Spring Semester Mid-term Examination For General Chemistry I

Date: Apr 21 (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 10 problems (page 13 - 14: Equation, constants & periodic table).** Please check all page numbers before taking the exam. Please write down the unit of your answer when **applicable**. You will get 30% deduction for a value that is missing its unit.

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

(채점 답안지 분배 및 이의신청 일정)

1. Period, Location, and Procedure

- 1) Return and Claim Period: Apr 26 (Mon 12:00~24:00)
- 2) **Location: Each class of Turnitin site (online)**
- 3) Procedure: If you have any claims on it, email them (Question# and reasons) to your TA.
(The claim is permitted only during the designated claim period. Keep that in mind! A solution file with answers for the examination will be uploaded on the web.)

2. Final Confirmation

- 1) Period: Apr 29-30 (Thu – Fri)
- 2) Procedure: During this period, you can check final score of the examination *on the website* again.
(No additional corrections. If no change in your score after reasoning, the claims were not accepted.)

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

1. (total 10 pts)

Elemental analysis of an unknown compound **A** yielded C_2H_4O as its empirical formula. Its mass was determined to be 44.03 g/mol. **A** did not contain any O-H bond, and did not contain a mirror plane in the molecular structure (i.e., the molecular structure is not symmetric). Answer the following questions.

(a) Give a chemical formula of **A**. (2 pts)

(Answer)

Molar mass of $C_2H_4O = 12 \cdot 2 + 1 \cdot 4 + 16 \cdot 1 = 44$. Thus the empirical formula should be the same as the chemical formula.

C_2H_4O

2 pts, no partial point

(b) Count the number of bonding electron pairs in **A** to satisfy the noble gas configuration. (4 pts)

(Answer)

Total number of valence electrons = $4 \cdot 2 + 1 \cdot 4 + 6 \cdot 1 = 18$ *+1 pt*

The number of electrons to satisfy the noble gas configuration = $8 \cdot 2 + 2 \cdot 4 + 8 \cdot 1 = 32$ *+1 pt*

The number of shared electrons should be $32 - 18 = 14$

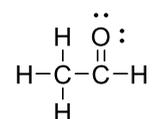
Thus the number of bonding electron pairs should be $14/2 = 7$ *full points for correct answer*

(no partial point for drawing structure)

(c) Construct a possible Lewis diagram of **A**. (4 pts)

(Answer)

Because there is no O-H bond, all hydrogen should be attached to C. The remaining three bonding pairs should connect C and O. The triangular conformation gives ethylene oxide, which has a mirror plane. Thus the connection should be linear and the excess bonding pair should be assigned to the C-O bond, yielding acetaldehyde.



+4 pts

If the connection is correct but the double bond or the lone pairs are not correct *+2 pts*

If the answer is ethylene oxide with the correct Lewis diagram *+2 pts*

If the answer is ethylene oxide with an incorrect Lewis diagram *+2 pts*

If the answer is vinyl alcohol with the correct Lewis diagram *+1 pt*

2. (total 10 pts)

Answer the following questions about ionization energy and electron affinity.

(a) Why is electron affinity of an atom always smaller than the corresponding ionization energy? Explain based on the meanings of ionization energy and electron affinity. (4 pts)

(Answer)

(1) Electron affinity is the energy required to detach the electron from the anion and give the neutral atom. Ionization energy is the energy necessary to remove an electron from a neutral atom and form positively charged ion. For ionization of the neutral atom, additional energy is required to remove an electron from the formed cation. +2 pts

(2) The anion has one more electron than the neutral atom. The additional electron gives the additional shielding effect of nuclear charge. +2 pts

-These are the second ionization energies (eV Atom^{-1}) of the 2nd period elements

Li, 75.64; Be, 18.21; B, 25.15; C, 24.38; N, 29.60; O, 35.12; F, 34.97; Ne, 40.96

(b) Why does Li have the largest second ionization energy among the 2nd period elements? (2 pts)

(Answer)

Li^+ has a noble gas configuration. Hence, releasing one more electron needs to break the shell, and requires large energy.

(c) Why does the second ionization energy increase from C to N and O? (2 pts)

(Answer)

From C^+ to N^+ and O^+ , the addition electrons go into the 2p orbitals. As the atomic number increases, the effective nuclear charge, Z_{eff} , generally increases. As a result, releasing electrons need more energy.

(d) Why does the second ionization energy slightly decrease from O to F? (2 pts)

(Answer)

F^+ must accommodate two electrons in the same 2p orbital, leading to greater electron-electron repulsion and diminished binding, thus more than compensating for the increased electron-nuclear interaction.

3. (total 10 pts)

Photons of wavelength 315 nm or shorter are needed to eject electrons from a surface of electrically neutral cadmium.

(a) What is the energy barrier that electrons must overcome to leave an uncharged piece of cadmium? (3 pts)

(Answer)

The energy barrier is the work function Φ_{Cd}

$$\Phi_{\text{Cd}} = E_{\text{photon, min}} = \frac{hc}{\lambda_{\text{max}}} = \{(6.626 \times 10^{-34} \text{Js})(2.998 \times 10^8 \text{ms}^{-1})\} / 315 \times 10^{-9} \text{m}$$
$$= 6.31 \times 10^{-19} \text{J} = 3.94 \text{eV} = 380 \text{kJ mol}^{-1}$$

(b) What is the maximum kinetic energy of electrons ejected from a piece of cadmium by photons of wavelength 200 nm? (3 pts)

(Answer)

$$E_{\text{photon}} = T_{\text{max}} + \Phi_{\text{Cd}}$$

$$T_{\text{max}} = E_{\text{photon}} - \Phi_{\text{Cd}} = \frac{hc}{\lambda} - 6.306 \times 10^{-19} \text{J}$$
$$= [\{(6.626 \times 10^{-34} \text{Js})(2.998 \times 10^8 \text{ms}^{-1})\} / 200 \times 10^{-9} \text{m}] - 6.306 \times 10^{-19} \text{J}$$
$$= 9.932 \times 10^{-19} \text{J} - 6.306 \times 10^{-19} \text{J}$$
$$= 3.63 \times 10^{-19} \text{J} = 2.26 \text{eV} = 218 \text{kJ mol}^{-1}$$

(c) Suppose the electrons described in (b) were used in a diffraction experiment. What would be their wavelength? (4 pts)

(Answer)

Momentum of the 2.26eV electrons \rightarrow corresponding wavelength

$$p_e = m_e v = \sqrt{m_e^2 v_{\text{max}}^2} = \sqrt{2m_e T}$$
$$= \sqrt{2(9.109 \times 10^{-31} \text{kg})(3.626 \times 10^{-19} \text{kgm}^2 \text{s}^{-2})} = 8.13 \times 10^{-25} \text{kgms}^{-1}$$
$$\lambda = h / p_e = 6.626 \times 10^{-34} \text{kg m}^2 \text{s}^{-1} / 8.13 \times 10^{-25} \text{kgms}^{-1} = 8.15 \times 10^{-10} \text{m} = 0.815 \text{nm}$$

4. (total 10 pts)

Without attempting a detailed calculation, let's try to estimate the first ionization energy for a ground state helium atom. Determine and explain the lowest and highest values possible.

(Answer)

We know that the orbitals have energies $E_n = -R \frac{Z^2}{n^2}$, where $R = -1312$ KJ/mol.

The energy needed to ionize the one electron from hydrogen's 1s orbital is therefore R:

$$I_1 = E_\infty - E_1 = 0 - (-R) = R$$

Now consider helium and its 1s electrons, attracted to a nucleus containing two protons ($Z=2$) competing for the same nuclear charge, the electrons screen one another. **+4 pts**

Lower limit: Pretend that each 1s electron screens the other completely, interposing a full charge of -1. If so, the screened electron sees roughly an effective nuclear charge of +1 ($Z_{\text{eff}}=2-1$). The lowest possible ionization energy is R, the value expected for a single electron bound to a nucleus with $Z_{\text{eff}}=1$.

+3 pts

(Illogical Z_{eff} only gets +2 pts)

Upper limit: At the other extreme, pretend that there is no screening at all. Assume that each electron interacts with the full nuclear charge so as to make $Z_{\text{eff}}=2$. The ionization energy, proportional to Z_{eff}^2 , then quadruples to 4R. Helium first ionization energy thus falls between R (1312KJ/mol) and 4R (5248kJ/mol).

+3 pts

(Illogical Z_{eff} only gets +2 pts)

For just simple comparison of ionization energy with other atoms,

+3 pts

5. (total 10 pts)

For the H atom, the transition from the 2p state to the 1s state is accompanied by the emission of a photon with an energy of 16.2×10^{-19} J. For an Fe atom, the same transition (2p to 1s) is accompanied by the emission of X-rays of 0.193 nm wavelengths.

(a) What is the energy difference between these states in iron? Compare this energy difference of Fe to that of H as ratio. (5 pts)

(Answer)

The 2p \rightarrow 1s transition in the Fe atom occurs with emission of x-rays of wavelength 0.193 nm. The energy of these x-rays is

$$E_{x\text{-rays}} = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{Js}) \times (2.9979 \times 10^8 \text{m/s})}{0.193 \times 10^{-9} \text{m}} = 1.03 \times 10^{-15} \text{J} = E_{2p, \text{Fe}} - E_{1s, \text{Fe}} \quad +4 \text{ pts}$$

$$\frac{E_{2p, \text{Fe}} - E_{1s, \text{Fe}}}{E_{2p, \text{H}} - E_{1s, \text{H}}} = \frac{1.03 \times 10^{-15} \text{J}}{16.2 \times 10^{-19} \text{J}} = 636 \quad +1 \text{ pt}$$

(b) Comment on the reason for the variation (if any) in the 2p-1s energy –level spacing for these two atoms. (5 pts)

(Answer)

This much larger spacing between the 2p and 1s states in Fe results from the larger nuclear charge ($Z=26$ for Fe vs. $Z=1$ for H). +2 pts

The larger Z lowers the energies of both the 2p and 1s in Fe compared to H, but lowers the energy of the 1s much more effectively because 1s electron feels more Z_{eff} than 2p electron. +3 pts

6. (total 10 pts)

Consider diatomic carbon (C_2) and chlorine (Cl_2) molecule.

If two electrons are removed from each molecule, how would the bond order change? Write down the LCAO MO notation for the molecules, and from which orbitals would the electrons be removed.

(Answer)

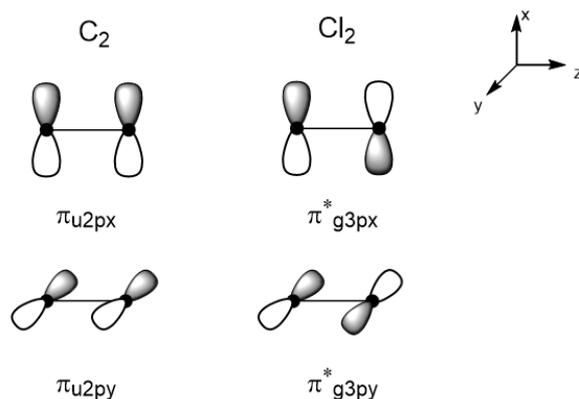
The electron configuration of C_2 and Cl_2 are:



The two electrons are removed from the $(\pi_{u2p})^4$, $(\pi_{g3p}^*)^4$ orbitals.

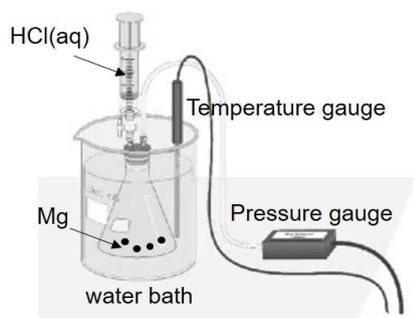
For C_2 , the electrons are removed from the bonding orbitals, so the bond order decreases from 2 to 1. **+2 pts**

For Cl_2 , the electrons are removed from the antibonding orbital, so the bond order increases from 1 to 2. **+2 pts**



7. (total 11 pts)

Joe carried out an experiment to measure the molar volume of a gas. He put magnesium powders to the flask in a water bath, and then drop the aqueous hydrochloric acid solution into it. He measured the pressure change during the reaction.



The results were:

Mass of magnesium powders 0.0110 g
Flask volume 123.5 mL
Final pressure 108 kPa
Initial pressure 99.3 kPa
Temperature constantly 291.75 K

(a) Calculate the molar amount of magnesium powders used in the reaction. (1 pt)

(Answer)

The molar amount of Mg is $0.0110\text{g}/24.305\text{g mol}^{-1} = 4.53 \cdot 10^{-4} \text{ mol}$

(b) Calculate the molar amount of hydrogen gas produced in the reaction. (2 pts)

(Answer)



mol of Mg reacted = mol of $\text{H}_2\text{(g)}$ produced

$$n = 4.53 \cdot 10^{-4} \text{ mol}$$

(c) Calculate the volume occupied by one mole of hydrogen gas (or molar volume) under the experimental condition. Ignore the volumes of Mg powders and HCl(aq). (2 pt)

(Answer)

According to the sample data,

$$V = 123.5 \text{ mL}$$

$$0.1235 \text{ L} / 4.53 \cdot 10^{-4} \text{ mol} = 273 \text{ L mol}^{-1}$$

(d) Convert the molar volume in (c) into the volume at the STP condition (273.15 K at 1 atm). Then compare the value with the accepted molar volume of an ideal gas at STP, vis. 22.4 Lmol⁻¹. (4 pts)

(Answer)

According to the sample data:

$$\Delta P = P_{H_2} = 8.7 \text{ kPa} \quad +1 \text{ pt}$$

Using the combined gas law to calculate the volume of H₂ at STP.

$$(8.7 \text{ kPa} * 123.5 \text{ mL}) / 291.75 \text{ K} = (101.3 \text{ kPa} * V) / 273.15 \text{ K}$$

$$V = 9.9 \text{ mL of H}_2 \text{ at STP} \quad +2 \text{ pt}$$

And then, calculate the molar volume of H₂ (g).

$$0.0099 \text{ L} / 4.53 * 10^{-4} \text{ mol} = 21.9 \text{ Lmol}^{-1}$$

The experimental molar volume at STP compares well with that of the ideal gas within the error of 2%.

+1 pt

(e) Why is the molar volume measured in the experiment similar to or different from that of the ideal gas? Explain it. (2 pts)

(Answer)

Hydrogen gas is composed non-polar, and the smallest molecules. The intermolecular forces are small, so that follows the ideal gas law well. Besides, the small partial pressure of the hydrogen gas in the experiment also gave the molar volume nearly identical to the ideal gas.

Full points for reasonable explanation

8. (total 9 pts)

Answer the following questions.

(a) A heteronuclear diatomic molecule has its root-mean-square speed of 515.4 m/s at 25°C. What is the molecule? (4 pts)

(Answer)

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}, \quad M = \frac{3RT}{v_{\text{rms}}^2}$$

Substitute $R=8.3145 \text{ J K}^{-1} \text{ mol}^{-1}$, $T=298.15 \text{ K}$, we get, $M = 0.028 \text{ kg/mol}$.

+2 pts

The molecule is CO.

full points for correct answer

(b) At 1 atm, how many times does single side of the 1 cm^2 wall collide with the molecules per second? Assume there is only one type of molecule which is the same one for problem (a). (5 pts)

(Answer)

$$v_{\text{rms}} = \sqrt{3} \bar{v}_x, \quad P = \frac{F}{A} = \frac{\Delta p_x}{A\Delta t} = \frac{\sum_i^N 2mv_{x,i}}{A\Delta t} = \frac{N \times 2m\bar{v}_x}{A\Delta t}$$

Therefore,

$$N = \frac{PA\Delta t}{2m\bar{v}_x} = \frac{101325 \text{ Pa} \times 1 \times 10^{-4} \text{ m}^2 \times 1 \text{ s}}{2 \left(\frac{0.028}{6.02 \times 10^{23}} \right) \text{ kg} \times 297.6 \text{ m/s}} = 3.66 \times 10^{23}$$

**full points for correct answer
(no partial point)**

If the answer used $Z_w = \frac{1}{4} \frac{N}{V} \bar{v} A$,

$$\begin{aligned} Z_w &= \frac{1}{4} \frac{N}{V} \bar{v} A = \frac{1}{4} (2.46 \times 10^{25} \text{ m}^{-3}) (474.82 \text{ m s}^{-1}) (1.00 \times 10^{-4} \text{ m}^2) \\ &= 2.92 \times 10^{23} \text{ s}^{-1} \end{aligned}$$

full points for correct answer

$$\bar{v} = \sqrt{\frac{8RT}{\pi M}} = 474.82 \text{ m/s}$$

+1 pts

$$\frac{N}{V} = \frac{N_A P}{RT} = 2.46 \times 10^{25} \text{ m}^{-3}$$

+2 pts

9. (total 10 pts)

After the rain, the water droplets can be found on the leaf like the below considering the surface tension for the water ($\gamma = 72.75 \text{ mN/m}$ at 25°C). And we often see the water strider on the pond.



(a) Can you imagine the shape of a water drop when the weather is very hot, at $\sim 50^\circ\text{C}$. And explain the reason why the shape is changed. (5 pts)

(Answer)

Because liquids with strong intermolecular interaction have high surface tension, the intermolecular interaction is weakened when the temperature increases (kinetic energy increases! if this KE is not included, 1pt will be taken.). **+3 pts**

Therefore, a water drop on the leaf can have the flattened shape compared to the initial condition. **+2 pts**

(b) Imagine the water strider on the low surface-tension-liquid like ethanol. ($\gamma = 22.8 \text{ mN/m}$ at 25°C) Can the water strider on the ethanol move easily compared with it on the water or not? Explain the reason. (5 pts)

(Answer)

When the water is replaced by the lower surface-tension liquid like ethanol, it could cause the water strider to drown. And it does not slide on the ethanol surface. **+3 pts**

By definition, the surface tension is the resistance of the surface of a liquid to an increase in its area. So, the weaker resistance of the ethanol in terms of surface tension, would not support floating striders on the surface. The similar is found on the contaminated pond by surfactant that can reduce the surface tension. **+2 pts**

10. (total 10 pts)

Answer the following questions.

(a) Phase changes occur between different solid forms, as well as from solid to liquid, liquid to gas, and solid to gas. When white tin at 1.00 atm is cooled below 13.2°C, it spontaneously changes (over a period of weeks) to gray tin. The density of gray tin is less than that of the white tin (5.75g cm⁻³ vs 7.31 g cm⁻³). Some white tin is compressed to a pressure of 2.00 atm. At this pressure, should the temperature be higher or lower than 13.2°C for the conversion to gray tin to occur? Explain your reasoning. (5 pts)

(Answer)

Gray tin is favored over white tin by lower temperature, **+1 pt**
but white tin is favored by higher pressure (because it is more dense than gray tin). **+1 pt**

Suppose the two forms of tin are present at equilibrium at 1 atm and 13.2 °C. Raising the pressure to 2 atm (eventually) converts all of the tin to white tin. **+1 pt**

In order to restore the gray allotrope the temperature must be adjusted in the direction that favors gray tin, that is, the temperature must be lowered below 13.2 °C **+2 pts**

(b) List the following substances in the order of increasing normal boiling points, T_b, and explain your reasoning: He, HF, NO, NH₄Cl, Ne. (5 pts)

(Answer)

He < Ne (heavier) < NO (weak dipole-dipole interaction) < HF (strong dipole-dipole interaction, hydrogen-bonding) < NH₄Cl (ionic interaction)

For correct order and correct reasoning, **5 pts**

Only correct order, no correct reasoning, **3 pts**

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.

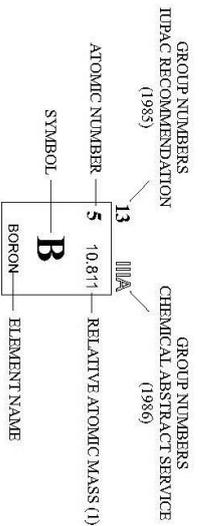
Conversion factors

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.kjrf-split.hr/periodni/en/>

GROUP		PERIOD																									
1	IIA											13	14	15	16	17	VIIIA										
1	H	2	IIIA											13	IVA	VA	VA	VIA	VIIA	18							
1	HYDROGEN	2	HELIUM											5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	Li	Be	B	C	N	O	F	Ne											13	14	15	16	17	18			
2	LITHIUM	BERYLLIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON											13	14	15	16	17	18			
3	Na	Mg	Al	Si	P	S	Cl	Ar											13	14	15	16	17	18			
3	SODIUM	MAGNESIUM	ALUMINIUM	SILICON	PHOSPHORUS	SULPHUR	CHLORINE	ARGON											13	14	15	16	17	18			
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr									
4	POTASSIUM	CALCIUM	SCANDIUM	TITANIUM	VANADIUM	CHROMIUM	MANGANESE	IRON	COBALT	NICKEL	COPPER	ZINC	GALLIUM	GERMANIUM	ARSENIC	SELENIUM	BROMINE	KRYPTON									
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe									
5	RUBIDIUM	STRONTIUM	YTRBIUM	ZIRCONIUM	NIOBIUM	MOLYBDENUM	TECHNETIUM	RUTHENIUM	RHODIUM	PALLADIUM	SILVER	CADMIUM	INDIUM	TIN	ANTIMONY	TELLURIUM	IODINE	XENON									
6	Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn									
6	CAESIUM	BARIUM	LANTHANIDE	HAFNIUM	TANTALUM	TUNGSTEN	RHENIUM	OSMIUM	IRIDIUM	PLATINUM	GOLD	MERCURY	THALLIUM	LEAD	BISMUTH	POLONIUM	ASTATINE	RADON									
7	Fr	Ra	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq									
7	FRANCIUM	RADIUM	ACTINIDE	RUTHERGIUM	DUBNIUM	SEABERGIUM	BOHRIUM	HASSIUM	METTERGIUM	UNUNNIUM	UNUNNIUM	UNUNNIUM	UNUNNIUM	UNUNNIUM	UNUNNIUM	UNUNNIUM	UNUNNIUM	UNUNNIUM									



(1) Pure Appl. Chem., 73, No. 4, 657-693 (2001)

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

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

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LANTHANIDE		ACTINIDE																			
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71							
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu							
LANTHANUM	CERUM	PRASEODYMIUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLMIUM	ERBIUM	THULIUM	Ytterbium	LUTETIUM							
138.91	140.12	140.91	144.24	(145)	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.04	174.97							
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103							
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	LAWRENCIUM							

2021 Spring Semester Final Examination For General Chemistry I

Date: Jun 16 (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 13 sheets with 10 problems (page 12-13: Equation, constants & periodic table).** Please check all page numbers before taking the exam. Please write down the unit of your answer when **applicable**. You will get 1 point 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: **June 19 (Sat, 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: **June 21 (Mon, 12:00 ~ 24:00)**
- Procedure: During this period, you can check final score of the examination *on the website* again.
(No additional corrections. If no change in your score after reasoning, the claims were not accepted.)

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

1. (total 12 pts)

Jin dissolved 2.2 g of a polymer in 100 mL of water at 25 °C. When he used a tube covered with a semipermeable membrane containing the polymer solution, the solution level increased up to the height of 11 cm from the original one.

(a) Calculate the osmotic pressure of the polymer solution. (2 pts)

(Note that the density of water is 1.0 g mL⁻¹ at 25 °C).

(Answer)

$$\pi = \rho g h = 1.0 \text{ g mL}^{-1} * 9.8 \text{ m s}^{-1} * 11 \text{ cm} = 1.0 \times 10^3 \text{ kg m}^{-3} * 9.8 \text{ m s}^{-1} * 0.11 \text{ m} = 1.1 \times 10^3 \text{ Pa}$$

+2 pts

(b) Estimate the average molar mass of the polymer. (4 pts)

(Answer)

$$c = \pi / RT = 1.1 \times 10^3 \text{ Pa} / (8.314 \text{ J mol}^{-1} \text{ K}^{-1} * 298 \text{ K}) = 4.4 \times 10^{-4} \text{ mol L}^{-1}$$

$$M(\text{polymer}) = \text{mass} / (c * V) = 2.2 \text{ g} / (4.4 \times 10^{-4} \text{ mol L}^{-1} * 0.10 \text{ L}) = 5.0 \times 10^4 \text{ g mol}^{-1} \quad +4 \quad \text{pts}$$

(no partial pts)

(c) Calculate the molality of the original polymer solution. (2 pts)

(Answer)

$$m(\text{polymer}) = 4.4 \times 10^{-5} \text{ mol} / (100 \text{ g}) = 4.4 \times 10^{-4} \text{ mol kg}^{-1} \quad \text{2 pts, unit should be included}$$

(d) Estimate the boiling point and the freezing point of the original polymer solution. K_b and K_f of water are 0.512 and 1.86 K kg mol⁻¹, respectively. (2 pts)

(Answer)

$$\Delta T_b = m * K_b = 4.3 \times 10^{-4} \text{ mol kg}^{-1} * 0.512 \text{ K kg mol}^{-1} = 2.2 \times 10^{-4} \text{ °C or K}$$

$$T_b = 100.00022 \text{ °C} \quad +1 \text{ pt}$$

$$\Delta T_f = m * K_b = 4.3 \times 10^{-4} \text{ mol kg}^{-1} * 1.86 \text{ K kg mol}^{-1} = 8.0 \times 10^{-4} \text{ °C or K}$$

$$T_f = -0.0008 \text{ °C} \quad +1 \text{ pt}$$

(e) Which colligative property is the best for estimating the molecular weight of the polymer? Explain it. (2 pts)

(Answer)

The temperature changes for boiling point elevation and freezing-point depression are too small to be measured; therefore, **the osmotic pressure** is fit to measure the molar mass of the polymers in a good precision. **+2 pts**

2. (total 6 pts)

Air in a bicycle pump is compressed by pushing in the handle. If the inner diameter of the pump is 8.0 cm and the pump is depressed 20 cm with a pressure of 3.00 atm,

(a) How much work is done in the compression? (4 pts)

(Answer)

Work is given by $w = -P_{ext}\Delta V$. The applied external pressure is known, and we need to consider the volume change.

$$\Delta V = -\pi r^2 d = -3.14 \times (4\text{cm})^2 \times 20\text{ cm} \times \left(\frac{1\text{L}}{1000\text{cm}^3}\right) = -1\text{L}$$

ΔV is negative because the air in the pump is compressed to a smaller volume; work is then

$$W = - (3\text{atm}) \times (-1\text{L}) \times \left(\frac{101.325\text{J}}{\text{L}\cdot\text{atm}}\right) = 304\text{ J} \quad \text{+4 pts (no partial pts)}$$

Where

Liter-atmosphere	1 L atm = 101.325 J (exactly)
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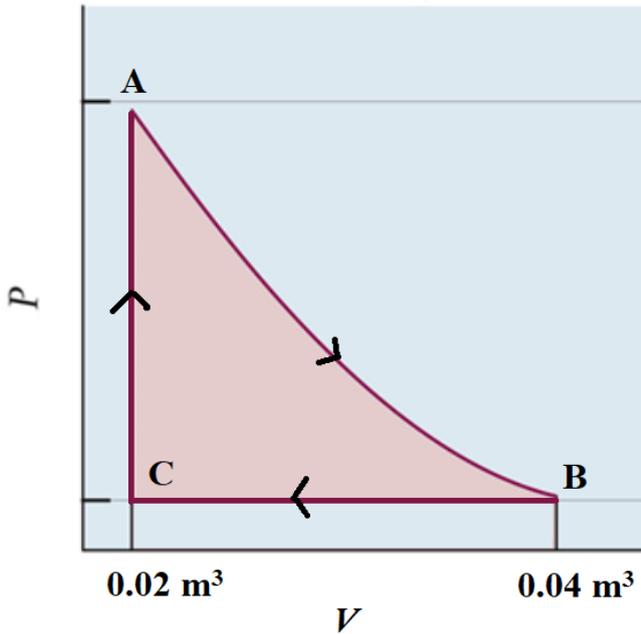
(b) Is the work positive or negative with respect to the air in the pump? (2 pts)

(Answer)

Work on the air is positive by convention as work is done on the air.

3. (total 12 pts)

Four moles of monatomic ideal gas goes through the cycle represented in following figure. Process A→B is a reversible isothermal expansion with temperature $T_A = 300$ K.



(a) Calculate P_A , P_B , and T_C , the pressures and temperature reached in A, B and C. (3 pts)

(Answer)

Process A→B is isothermal, so $T_A = T_B$

$$P_A = nRT_A/V_A = 498.8 \text{ kPa} \quad \mathbf{1 \text{ pt}}$$

$$P_B = nRT_B/V_B = 249.4 \text{ kPa} \quad \mathbf{1 \text{ pt}}$$

And $P_C = P_B$ and $V_C = V_A$, so

$$T_C = P_C V_C / nR = 150 \text{ K} \quad \mathbf{1 \text{ pt}}$$

(correct answer 1 pt,

Partial point 0.5 pt for correct equation

Unit missing 0.5 pt)

(b) Fill the following table with numerical values in Joules. (9 pts)

Process	ΔU	q	w
A→B			
B→C			
C→A			

(Answer)	1 pt for each		
Process	ΔU	q	w
A→B	0	6915	-6915
B→C	-7483	-12471	4988
C→A	7483	7483	0

1) A→B

Isothermal, so $\Delta U = 0$

In the reversible process

$$w = - \int_{V_A}^{V_B} P dV = -nRT \int_{V_A}^{V_B} \frac{1}{V} dV = -nRT \ln\left(\frac{V_B}{V_A}\right)$$

$$w = - 6915 \text{ J}$$

$$q = -w = 6915 \text{ J}$$

2) B→C

$$w = -P\Delta V = 4988 \text{ J}$$

$$\Delta U = 3/2nR\Delta T = - 7483 \text{ J}$$

$$q = \Delta U - w = -12471 \text{ J}$$

3) C→A

$w = 0$ because the volume is constant

$$q = \Delta U = 3/2nR\Delta T = - 7483 \text{ J}$$

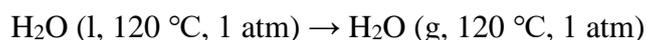
(correct answer 1 pt,

Wrong sign with correct answer 0.5 partial pt

Wrong answer but correct work shown 0.5 partial pt

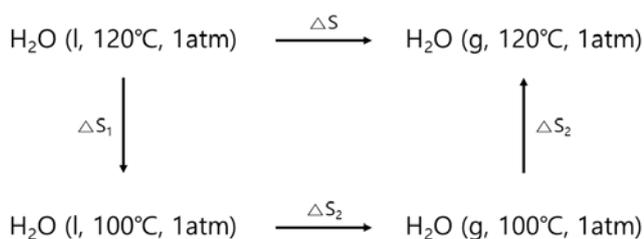
4. (total 10 pts)

Calculate the molar entropy change ΔS for the following process,



The enthalpy of vaporization of $\text{H}_2\text{O}(\text{l})$ at 100°C is $40,580 \text{ J}\cdot\text{mol}^{-1}$. The molar heat capacity of $\text{H}_2\text{O}(\text{l})$ is $75.3 \text{ J}\cdot\text{K}^{-1} \text{ mol}^{-1}$ and the molar heat capacity of $\text{H}_2\text{O}(\text{g})$ is $36.0 + 0.013 T \text{ J}\cdot\text{K}^{-1}\text{mol}^{-1}$ where T is absolute temperature.

(Answer)



+2 pts

$$\Delta S_1 = \int_{393}^{373} \frac{C_{p,l}}{T} dT = 75.3 \ln \frac{373}{393} = -3.93 \text{ J/K} \cdot \text{mol}$$

+2 pts

$$\Delta S_2 = \frac{\Delta H_{\text{vap}}}{T} = \frac{40580}{373} = 108.83 \text{ J/K} \cdot \text{mol}$$

+2 pts

$$\Delta S_3 = \int_{373}^{393} \frac{C_{p,g}}{T} dT = \ln \frac{36+0.013T}{T} dT = 2.14 \text{ J/K} \cdot \text{mol}$$

+2 pts

$$\Delta S = \Delta S_1 + \Delta S_2 + \Delta S_3 = 107.04 \text{ J/K} \cdot \text{mol}$$

+2 pts

If the answer is correct and the work is shown, give full points,
If the answer is incorrect give partial points for the correct parts.

5. (total 10 pts)



An equilibrium mixture composed of NO, N₂O, and NO₂ displays a brownish color because of NO₂. Predict & explain whether the color of the mixture will fade or darken when the following stresses are introduced. NO and N₂O are colorless. The reaction as written above is exothermic. (2 pts each)

(a) The volume of the equilibrium mixture is reduced at constant temperature.

(Answer) (explanation 1 pt, answer 1 pt)

The stress is the reduction in volume. The partial pressures of all the compounds will momentarily rise. The equilibrium will then shift in such a way as to reduce the number of molecules of gas in the container and reduce the total pressure. The equilibrium will thus shift from left to right and thus the brown color of the mixture will darken as more NO₂ is produced.

(b) The equilibrium mixture is warmed up.

(Answer) (explanation 1 pt, answer 1 pt)

The reaction is exothermic. Warming the system will shift the equilibrium from right to left and thus the color of the mixture will fade.

(c) NO(g) is added to the equilibrium mixture without change of volume or temperature.

(Answer) (explanation 1 pt, answer 1 pt)

The stress is the addition of NO. The system reacts to decrease the concentration of NO. Thus the reaction proceeds from left to right and the brown color of the reaction mixture will darken.

(d) Ar(g), which is inert, is added to the equilibrium mixture without changing the volume.

(Answer) (explanation 1 pt, answer 1 pt)

The partial pressures of the reacting gases are unaffected by the addition of an inert gas and thus the equilibrium will not shift. There is no color change.

(e) Ar(g) is added to the equilibrium mixture without changing the total pressure and the temperature.

(Answer) (explanation 1 pt, answer 1 pt)

In order to maintain a constant pressure, the volume of the system must have increased. Thus, the reaction will shift from right to left and the color of mixture will fade.

6. (total 10 pts)

The reaction of $\text{CaCO}_3(\text{s})$ to produce $\text{CaO}(\text{s})$ and $\text{CO}_2(\text{g})$ has an equilibrium constant at 25°C of 2×10^{-23} . Values of ΔH°_f are as follows: CaCO_3 , -1207.6 kJ/mol ; CaO , -634.9 kJ/mol ; and CO_2 , -393.5 kJ/mol .

(a) What is ΔG° for this reaction? (2 pts)

(Answer)

$$\Delta G^\circ = -RT \ln K = -(8.314 \text{ J K}^{-1} \text{ mol}^{-1})(298 \text{ K}) \ln(2 \times 10^{-23}) = 129.5 \text{ kJ mol}^{-1}$$

(b) What is the equilibrium constant at 900°C ? (4 pts)

(Answer)

$$\Delta H^\circ = \Delta H^\circ_f(\text{CaO}) + \Delta H^\circ_f(\text{CO}_2) - \Delta H^\circ_f(\text{CaCO}_3) = (-634.9 \text{ kJ/mol}) + (-393.5 \text{ kJ/mol}) - (-1207.6 \text{ kJ/mol}) = 179.2 \text{ kJ mol}^{-1}$$

$$\ln \frac{K_2}{K_1} = -\frac{\Delta H^\circ}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) = -\frac{179.2 \text{ kJ mol}^{-1}}{8.314 \text{ J K}^{-1} \text{ mol}^{-1}} \left(\frac{1}{1173 \text{ K}} - \frac{1}{298 \text{ K}} \right) = 53.95$$

$$K_2 = K_1 \exp(53.95) = (2 \times 10^{-23}) \exp(53.95) = 5.39 \quad +2 \text{ pts (no partial pts)}$$

(c) What is the partial pressure of $\text{CO}_2(\text{g})$ in equilibrium with CaO and CaCO_3 at 900°C ? (2 pts)

(Answer)

$$K_2 = P_{\text{CO}_2} = 5.39 \text{ atm}$$

(d) Are reactants or products favored at the lower temperature? at the higher temperature? (2 pts)

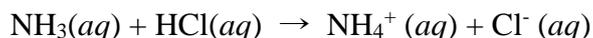
(Answer)

K is larger at high temperature.

Products are favored at high T; reactants are favored at low T.

7. (total 10 pts)

Ammonia is a weak base with a K_b of 1.8×10^{-5} . A 140.0 mL sample of a 0.175 M solution of aqueous ammonia is titrated with a 0.106 M solution of the strong acid HCl. The reaction is

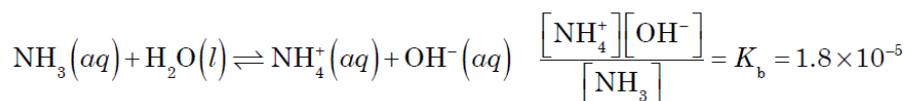


Compute the pH of the titration solutions with the following conditions at 25°C:

(a) before any acid is added. (2 pts)

(Answer)

The original solution (before any titrating acid is added) is 0.175 M aqueous NH_3 . Ammonia acts as a base in water



If the equilibrium concentration of NH_4^+ is x , then the equilibrium concentration of NH_3 is $0.175 - x$; and that of OH^- is x . The other sources of OH^- are negligible. Substitution and solving for x (by iteration) gives $[\text{OH}^-] = 1.766 \times 10^{-3}$ M and a pH of 11.25.

+2 pts

(b) when the titration is at the half-equivalence point. (2 pts)

(Answer)

Text section 15.6 shows that in the titration of a weak acid with a strong base, the pH at the half-equivalence point is very close to the $\text{p}K_a$ of the weak acid: $\text{p}K_a = \text{pH}$. Construct the analogous relationship $\text{p}K_b = \text{pOH}$ to apply to the titration of a weak base with a strong acid. Then, $\text{pH} = 14.00 - \text{pOH} = 14.00 - 4.745 = 9.26$

+2 pts

For a, b,

Wrong substitution or equation, 0 pt

Mistake in calculation, 1 pt

Correct but given pOH, 1 pt

(c) when the titration is at the equivalence point. (3 pts)

(Answer)

It requires $(0.175/0.106)(140.0) = 231.13$ mL to titrate the solution to the equivalence point, at which point the total volume of the solution is 371.13 mL. The solution is in effect dilute aqueous NH_4Cl in which the concentration of the NH_4^+ ion is nominally $0.175(140.00/371.13) = 0.0660$ M. This concentration is lowered slightly by the reaction of the NH_4^+ ion with water to generate H_3O^+ and NH_3 . The K_a for this reaction is

$$\frac{K_w}{K_b} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.56 \times 10^{-10}$$

Substituting in the usual way into the equilibrium expression for this acid ionization gives $[\text{H}_3\text{O}^+] = 6.06 \times 10^{-6}$ M, pH = 5.22.

+3 pts

(d) when the titration is 1.00 mL past the equivalence point. (3 pts)

(Answer)

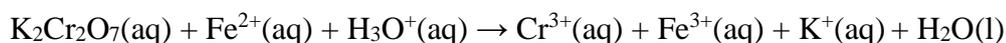
When the titration is 1.00 mL past the equivalence point, the NH_4^+ is still present but is completely overshadowed as a source of H_3O^+ by the excess $\text{HCl}(aq)$. Consider only the HCl. The first 231.13 mL of 0.106 M HCl were neutralized, so the effective concentration of HCl in the solution is the amount of HCl contributed by the last 1.00 mL divided by the total volume of the solution. This is $(1.00/372.13)(0.106) = 2.85 \times 10^{-4}$ M. This is also the concentration of H_3O^+ so the pH is 3.55.

+3 pts

8. (total 10 pts)

Potassium dichromate in acidic aqueous solution is used to titrate an aqueous solution of iron(II) ions.

(a) Balance the following equation, and write the oxidation number above the symbol of potassium dichromate. (2 pts)



(Answer)



(b) Split the whole reaction into two half-equations for $\text{K}_2\text{Cr}_2\text{O}_7$ and Fe^{2+} , including electrons involved in each half-reaction. (4 pts)

(Answer)



(c) If 40.00 mL of the 100 mM Fe^{2+} solution was found to be equivalent to 25.00 mL of the potassium dichromate solution, calculate the mass of potassium dichromate. (2 pts)

(Answer)

$$40.00\text{mL} \times 100 \text{ mM} = 25.00\text{mL} \times X \text{ mM} \times 6$$

$$\text{Concentration of potassium dichromate} = X = 26.7\text{mM}$$

$$\text{Mass of potassium dichromate} = M_w \times X \times V = 294.1846 \times 0.0267\text{M} \times 0.025\text{mL} = \mathbf{0.196 \text{ g}} \quad +2 \text{ pt}$$

(d) The standard Gibbs free energy change for the reaction is given as -324 kJ mol^{-1} . Calculate E°_{cell} , and write the cell configuration consistent with the E°_{cell} value using the line notation. (2 pts)

(Answer)

$$\Delta G^\circ = -nFE^\circ_{\text{cell}} \text{ and } n = 6 \text{ thus } E^\circ_{\text{cell}} = 0.56 \text{ V.} \quad +1 \text{ pt}$$

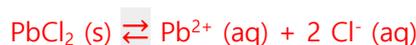


9. (total 10 pts)

Attempting to dissolve 0.50 g PbCl₂ in 50 mL of water, a chemist finds 0.28 g of the solid remains in solution at a temperature of 25 °C.

(a) Estimate the value of the solubility product constant, K_{sp} (25 °C), for PbCl₂ (Mw=278.1 g/mol). (2 pts)

(Answer)



$$K_{\text{sp}} = [\text{Pb}^{2+}][\text{Cl}^-]^2$$

If 0.28 g PbCl₂ remains undissolved in a volume of 50 mL, then evidently 0.22 g must have gone into solution.

$$\begin{aligned} \frac{0.22 \text{ g}}{50 \text{ mL}} \times \frac{1000 \text{ mL}}{\text{L}} &= 4.4 \text{ g/L} \\ \frac{4.4 \text{ g PbCl}_2}{\text{L}} \times \frac{1 \text{ mol PbCl}_2}{278.1 \text{ g}} \times \frac{1 \text{ mol Pb}^{2+}}{1 \text{ mol PbCl}_2} &= 0.0158 \text{ mol Pb}^{2+} / \text{L} \\ \frac{4.4 \text{ g PbCl}_2}{\text{L}} \times \frac{1 \text{ mol PbCl}_2}{278.1 \text{ g}} \times \frac{2 \text{ mol Cl}^-}{1 \text{ mol PbCl}_2} &= 0.0316 \text{ mol Cl}^- / \text{L} \\ K_{\text{sp}} = [\text{Pb}^{2+}][\text{Cl}^-]^2 &= (0.0158)(0.0316)^2 = 1.6 \times 10^{-5} \end{aligned}$$

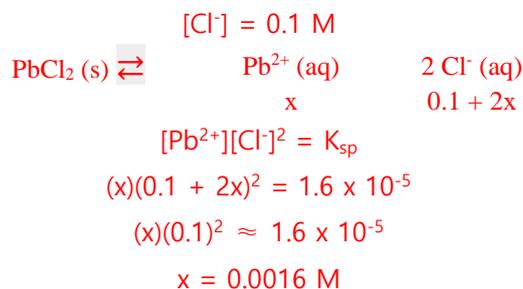
(b) Compute the amount of PbCl₂ that can be dissolve in 0.1 L of water. (1 pts)

(Answer)

0.44 g

c) Calculate the amount of PbCl₂ that will dissolve in a 50mL of 0.1 M solution of KCl. (3 pts)

(Answer)



dissolved concentration of Pb²⁺ falls 10-fold (from 0.016 M to only 0.0016 M).

~0.022 g

+3 pts (no partial pts)

d) NaCl and NaI are mixed together to produce a solution 0.01 M in both Cl⁻ and I⁻. 0.001 mole of Pb(NO₃)₂ was added to 1.0 L of the NaCl/NaI solution. Will either PbCl₂ or PbI₂ be precipitated? (K_{sp} of PbI₂ is 8.5×10⁻⁹) (4 pts)

(Answer)



Initial concentrations in a volume of 1.0 L,

$$[\text{Cl}^{-}] = 0.01 \text{ M}$$

$$[\text{I}^{-}] = 0.01 \text{ M}$$

To this mixture is then added 0.001 mole of Pb²⁺, producing an initial Pb²⁺ concentration of 0.001 M ([Pb²⁺] = (0.001 mol) / (1.0 L) = 0.001 M).

From here we compute the reaction quotient for PbI₂,

$$Q = [\text{Pb}^{2+}][\text{I}^{-}]^2 = (0.001)(0.01)^2 = 1.0 \times 10^{-7}$$

+1 pt

PbI₂ must precipitate so that [Pb²⁺][I⁻]² becomes equal to K_{sp}(PbI₂) = 8.5 × 10⁻⁹.

+1 pt

For PbCl₂, more soluble than PbI₂,

$$Q = [\text{Pb}^{2+}][\text{Cl}^{-}]^2 = (0.001)(0.01)^2 = 1.0 \times 10^{-7}$$

+1 pt

remains well below the equilibrium value K_{sp}(PbCl₂) = 1.6 × 10⁻⁵.

No PbCl₂ precipitation

+1 pt

If the answer is correct and the work is shown, give full points,

If the answer is incorrect give partial points for the correct parts.

(Only answer written, 0 pts,

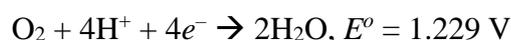
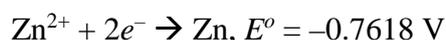
Q calculated, compared with K_{sp} but wrong answer for K_{sp} of PbCl₂, +1 pt

Equilibrium considered and both considered, full point)

10. (total 10 pts)

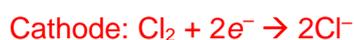
In a galvanic cell, the first half-cell consists of gaseous chlorine bubbled over a platinum electrode at a pressure of 1.00 atm into a 1.00 M solution of ZnCl_2 and pH 0. The second half-cell has a strip of solid gallium immerse in a 1.00 M $\text{Ga}(\text{NO}_3)_3$ solution. The initial cell potential for combination of two half cells is measured to be 1.918 V at 25 °C, and as the cell operates, the concentration of chloride ion is observed to increase.

The followings are half-reaction potentials:



(a) Write balance equations for the half-reactions at the anode and the cathode. (2 pts)

(Answer)



+2 pts

(b) Calculate the standard reduction potential of a $\text{Ga}^{3+}|\text{Ga}$ half-cell. (2 pts)

(Answer)

$$E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = 1.3583 \text{ V} - x \text{ V} = 1.918 \text{ V}, \quad x = -0.5597 \text{ V}$$

+2 pts

(c) The cell becomes an electrolytic cell when the concentration of 1.00 M of ZnCl_2 at the first half-cell is reduced to 0.1 M, pH is adjusted to 7, and gaseous chlorine bubble is stopped. Write balance equations for the half-reactions at the first half-cell as the cathode and calculate cell potential. (6 pts)

(Answer)

$$(i) E(\text{Cl}_2|\text{Cl}^-) = 1.3583 \text{ V} - (0.0592 \text{ V}/2)\log((0.1)^2/1) = 1.4175 \text{ V}$$

$$\rightarrow E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = 1.4175 \text{ V} - (-0.5597 \text{ V}) > 0 : \text{galvanic cell (X)}$$

$$(ii) E(\text{H}^+/\text{H}_2) = 0.00 \text{ V} - (0.0592 \text{ V} /2)\log(1/(10^{-7})^2) = -0.4144 \text{ V}$$

$$\rightarrow E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = -0.4144 \text{ V} - (-0.5597 \text{ V}) > 0 : \text{galvanic cell (X)}$$

$$(iii) E(\text{Zn}^{2+}|\text{Zn}) = -0.7618 \text{ V} - (0.0592 \text{ V}/2)\log(1/0.1) = -0.7914 \text{ V}$$

$$\rightarrow E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = -0.7914 \text{ V} - (-0.5597 \text{ V}) = -0.2317 \text{ V} : \text{electrolytic cell}$$



+4 pts



+2 pts

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