2018 SPRING Semester Midterm Examination
For General Chemistry I

Date: April 18 (Wed),   Time Limit: 19:00 ~ 21:00

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

Professor Name	Class	Student I.D. Number	Name

Problem	points	Problem	points	TOTAL pts
1	/8	**6**	/10	
2	/11	**7**	/11	
3	/6	**8**	/11	**/100**
4	/10	**9**	/12	
5	/10	**10**	/11	

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

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

NOTICE: SCHEDULES on RETURN and CLAIM of the MARKED EXAM PAPER.
(채점답안지 분배 및 이의신청 일정)

 1. Period, Location, and Procedure

1)   Return and Claim Period: *April 23 (Mon, 19: 00 ~ 20:00 p.m.)*

2)   *Location: Room for quiz session*

3)   Procedure:

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

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

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

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

2. Final Confirmation

1) Period: April 26 (Thu) – April 27 (Fri)

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

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

1. (total 8 pts) An ionic compound used as a chemical fertilizer has the composition (by mass) 48.46% O, 23.45% P, 21.21% N, 6.87% H.

(a) Give <u>the name and chemical formula</u> of the compound. Note that this compound contains ammonium ions.

  (Answer)

(b) Draw <u>Lewis diagrams</u> for the two types of ions that make it up.

  (Answer)

2. (total 11 pts) An unknown gas molecule XF_3 which consists of mysterious atom X as a central atom is given to you to be identified. The only clue is that X is known to be one of period 3 (from Na to Ar) elements.

(a) Monomer XF_3 has a stable Lewis structure without any formal charges on atoms. Also, there is no radical (an atom that has an unpaired valence electron) in this molecule. Give all the available XF_3 molecules. (Note that the central atom X may satisfy or not satisfy the octet rule.)

   (Answer)

(b) Draw a Lewis diagram and name the approximate molecular geometry for every available XF_3 molecule from problem (a) based on VSEPR.

   (Answer)

(c) To identify this unknown molecule XF_3, total dipole moment of given molecule was measured. In result, XF_3 molecule is identified to be non-polar. Among the molecules from the answer of problem (a), identify all the available XF_3 molecule(s).

   (Answer)

3. (total 6 pts) Suppose we picture an electron in a chemical bond as being a wave with fixed ends. Take the length of the bond to be 1.0 Å.

(a) Calculate <u>the wavelength</u> of the electron wave in its <u>ground state</u> and in its <u>first excited state</u>.

  (Answer)

(b) <u>How many nodes</u> does the <u>first excited state</u> have?

  (Answer)

4. (total 10 pts) Light with a wavelength of 525 nm strikes the surface of cesium in a photocell. The work function of cesium is 3.43×10^{-19} J.

(a) Calculate the <u>maximum velocity</u> of the photoelectrons.

  (Answer)

(b) Compute the <u>de Broglie wavelength</u> for the photoelectron in (a).

  (Answer)

(c) Determine the <u>longest wavelength of light</u> that is capable of ejecting electrons from the surface of cesium.

  (Answer)

5. (total 10 pts) The motion of an electron in a bond can be treated crudely as motion in an one-dimensional box. Consider electrons in O_2 and ozone. Note that the lengths of the O-O and O=O bonds are 1.48 and 1.21 Å, respectively

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

   (Answer)

(b) Calculate <u>the wavelength of light</u> necessary to excite the electron from its <u>ground state</u> to the <u>first excited state</u>.

   (Answer)

6. (total 10 pts) The ionization energy of a 1s electron of an hydrogen atom is 2.18 X 10^{-18} joule (or 1312 KJ/mol).

(a) What is the <u>ionization energy of a 2p electron</u> of a hydrogen atom?

   (Answer)

(b) What is the <u>ionization energy of a 1s electron</u> of a He^+ ion?

   (Answer)

(c) Without attempting a detailed calculation, determine the <u>lowest and highest first ionization energy values</u> possible for a ground-state helium atom.

   (Answer)

7. (total 11 pts) One orbital of a hydrogen atom is

$$\psi = re^{-r/2a} \sin\theta \cos\phi$$

(a) Show that this <u>satisfies the Schrödinger equation</u>,

$$-\frac{\hbar}{2m_e}\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\phi^2}\right]\psi - \frac{e^2}{4\pi\varepsilon_0}\frac{1}{r}\psi = E\psi$$

and obtain the corresponding <u>energy eigenvalue E</u> in the unit of eV. To solve this problem, you will need $a = 4\pi\varepsilon_0\hbar^2/(e^2 m_e)$, or equivalently $e^2/(4\pi\varepsilon_0) = \hbar^2/(m_e a)$. Also, $h = 2\pi\hbar$.

(Answer)

(b) <u>How many radial nodes</u> does this function have?

(Answer)

(c) Sketch <u>the 3-dimensional shape</u> of this orbital.

(Answer)

8. (total 11 pts) Below is the measured photoelectron spectrum for neon excited by X-rays with wavelength 9.890 Å. Answer the following questions.

(a) Write <u>the electron configuration</u> of neon.

   (Answer)

(b) Calculate <u>the ionization energy for each kinetic energy</u> detected from the above spectrum and write the corresponding atomic orbital.

   (Answer)

(c) Estimate <u>the value of Z_{eff}</u> for neon in each orbital.

   (Answer)

9. (total 12 pts) Consider heteronuclear diatomic molecule NO.

(a) Describe its <u>magnetic property</u>.

   (Answer)

(b) Provide its <u>correlation diagram</u>.

   (Answer)

(c) Sketch <u>the shape of the highest occupied molecular orbital</u>. Do not forget to specify the nuclear centers by N or O.

   (Answer)

10. (total 11 pts) Use valence bond (VB) theory to answer the following questions.

(a) Draw the molecular structure of allene ($H_2C=C=CH_2$). Using this molecular structure, show hybridization modes of all carbons.

(Answer)

(b) Sketch the σ and π frameworks of allene. Show all hybrid orbitals and p orbitals and assign σ and π-bonds clearly.

(Answer)

(c) Construct a putative molecular orbital diagram for the π-system. Sketch π-MOs and label them with π, π* or $π_{nb}$.

(Answer)

Physical Constants

Avogadro's number	$N_A = 6.02214179 \times 10^{23}$ mol^{-1}
Bohr radius	$a_0 = 0.52917720859$ Å $= 5.2917720859 \times 10^{-11}$ m
Boltzmann's constant	$K_B = 1.3806504 \times 10^{-23}$ J K^{-1}
Electronic charge	$e = 1.602176487 \times 10^{-19}$ C
Faraday constant	$F = 96485.3399$ C mol^{-1}
Masses of fundamental particles:	
Electron	$m_e = 9.10938215 \times 10^{-31}$ kg
Proton	$m_P = 1.672621637 \times 10^{-27}$ kg
Neutron	$m_n = 1.674927211 \times 10^{-27}$ kg
Permittivity of vacuum	$\varepsilon_o = 8.854187817 \times 10^{-12}$ C^{-2} J^{-1} m^{-1}
Planck's constant	$h = 6.62606896 \times 10^{-34}$ J s
Ratio of proton mass to electron mass	$m_P / m_e = 1836.15267247$
Speed of light in a vacuum	$c = 2.99792458 \times 10^{8}$ m s^{-1} (exactly)
Standard acceleration of terrestrial gravity	$g = 9.80665$ m s^{-2} (exactly)
Universal gas constant	$R = 8.314472$ J mol^{-1} K^{-1} $= 0.0820574$ L atm mol^{-1} 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 Å $= 10^{-10}$ m
Atomic mass unit	1 u $= 1.660538782 \times 10^{-27}$ kg
	1 u $= 1.492417830 \times 10^{-10}$ J $= 931.494028$ MeV (energy equivalent form $E = mc^2$)
Calorie	1 cal $= 4.184$ J (exactly)
Electron volt	1 eV $= 1.602177 \times 10^{-19}$ J $= 96.485335$ kJ mol^{-1}
Foot	1 ft $= 12$ in $= 0.3048$ m (exactly)
Gallon (U. S.)	1 gallon $= 4$ quarts $= 3.785412$ L (exactly)
Liter	1 L $= 10^{-3}$ m^{-3} $= 10^{3}$ cm^3 (exactly)
Liter–atmosphere	1 L atm $= 101.325$ J (exactly)
Metric ton	1 t $= 1000$ kg (exactly)
Pound	1 lb $= 16$ oz $= 0.4539237$ kg (exactly)
Rydberg	1 Ry $= 2.17987197 \times 10^{-18}$ J $= 1312.7136$ kJ mol^{-1} $= 13.60569193$ eV
Standard atmosphere	1 atm $= 1.01325 \times 10^{5}$ Pa $= 1.01325 \times 10^{5}$ kg m^{-1} s^{-2} (exactly)
Torr	1 torr $= 133.3224$ Pa

PERIODIC TABLE OF THE ELEMENTS

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

Key:

ATOMIC NUMBER (IUPAC RECOMMENDATION 1985)	GROUP NUMBERS IUPAC RECOMMENDATION (1985)	GROUP NUMBERS CHEMICAL ABSTRACT SERVICE (1986)
5	13	IIIA
B	10.811	RELATIVE ATOMIC MASS (1)
BORON	SYMBOL	ELEMENT NAME

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

LANTHANIDE

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

ACTINIDE

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

Claim Form for General Chemistry Examination

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

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

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

<The Answers>

Problem	points	Problem	points	TOTAL pts
1	4+4/8	**6**	4+2+4/10	
2	3+6+2/11	**7**	6+2+3/11	
3	4+2/6	**8**	2+3+6/11	**/100**
4	4+3+3/10	**9**	3+6+3/12	
5	6+4/10	**10**	3+4+4/11	

단순히 계산이 틀리거나 unit 이 맞지 않지만 내용이 모두 맞았을 때 – 1 pt

1. (total 8 pts)

(a) (4 pts) chemical formula 3 pts; name 1 pt

　　　　Although the chemical formula is different, the rational answer can get full points.

Assume 100.00 g of compound, and find the chemical amounts of each of the elements by dividing masses by molar masses

$$\frac{48.46 \ g \ O}{15.9994 \ g \ mol^{-1}} = 3.029 \ \text{mol O} \qquad \frac{23.45 \ g \ P}{30.97376 \ g \ mol^{-1}} = 0.7571 \ \text{mol P}$$

$$\frac{21.21 \ g \ N}{14.0067 \ g \ mol^{-1}} = 1.514 \ \text{mol N} \qquad \frac{6.87 \ g \ H}{1.00794 \ g \ mol^{-1}} = 6.816 \ \text{mol H}$$

Divide each by the smallest one to find the formula $PO_4N_2H_9$, which is **$(NH_4)_2HPO_4$, or ammonium hydrogen phosphate.**

(b) (4 pts) ammonium ion 2 pts; hydrogen phosphate 2 pts

　　　This answer follows the answer of problem 1(a).

The Lewis structures of the two ions are
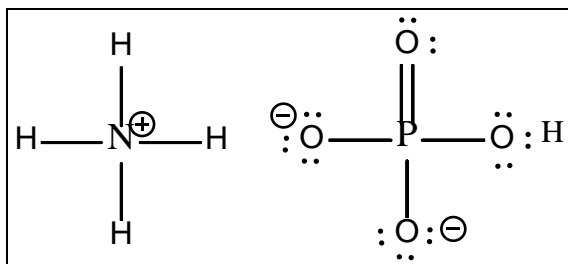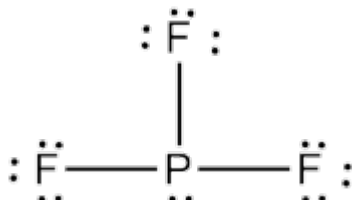
2. (total 11 pts)

(a) (3 pts)

AlF_3, PF_3, ClF_3

(b) (6 pts) for each, 2 pt of Lewis diagram; 1 pt for geometry

AlF_3 PF_3 ClF_3
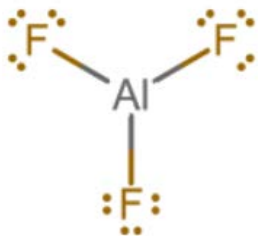
Trigonal Planar   **Trigonal pyramidal**   **T (T-Shape)**

(c) (2 pts)

AlF_3
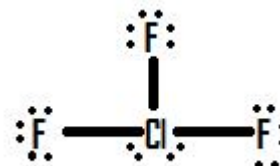
3. (total 6 pts)

(a) (4 pts) for each, 2 pts

In the ground state, one half-wavelength fits along the length of the bond, which is 1.0 Å. **Hence l_1 = 2.0 Å.**

In the first excited state (n = 2), two half-wavelengths fit: **l_2 = 1.0 Å.**

(b) (2 pts)

The number of nodes is one less than the quantum number describing the standing wave. Hence, there is **1 node** in the wave-function of the n = 2 state (the first excited state).

4. (total 10 pts)

(a) (4 pts)

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

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

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

(b) (3 pts)

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

(c) (3 pts)

The longest wavelength to promote the photoelectric effect for cesium occurs when the light energy matches the work function since $E_{max} = \dfrac{1}{2}mv_e^2 = h\nu - \Phi$.

$$\Phi = 3.43 \times 10^{-19}\ J = h\nu_0 = hc/\lambda_0$$

λ_0 = (6.626 x 10^{-34} J s x 3.00 x 10^8 m s^{-1})/3.43 x 10^{-19} J = 5.80 x 10^{-7} m or **580 nm**.

5. (total 10 pts)

(a) (6 pts) for each, 1 pt

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

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

The particle in this case is an electron, m is known. The box length of O_2 is 1.21 $\times 10^{-10}$ m and that of

ozone with the resonance structures of is (1.21+1.48) $\times 10^{-10}$ m. For n=1,2,3,

O_2; **E_1=4.12*10^{-18} J, E_2=16.5*10^{-18} J, E_3=37.0*10^{-18} J**
O_3; **E_1=0.83*10^{-18} J, E_2=3.33*10^{-18} J, E_3=7.49*10^{-18} J**

(b) (4 pts) for each, 2 pts

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

$\lambda = \dfrac{hc}{E_2 - E_1}$

for O2, 1.61*10^{-8} m = 16.1 nm
for O3, 7.95*10^{-8} m = 79.5 nm

6. (total 10 pts)

(a) (4 pts)

To ionize the atom, we must supply sufficient energy to promote the electron from n=1 to n=∞

$$E_n = -\frac{e^2}{2a_0}\frac{Z^2}{n^2} = -(2.18 \times 10^{-18}J)\frac{Z^2}{n^2}$$

The ionization energy is therefore

$E_\infty - E_1 = -(2.18 \times 10^{-18}$ J) Z^2 $(\frac{1}{\infty^2} - \frac{1}{1^2}) = 2.18 \times 10^{-18}$ J (Z^2)

For 2p electron of hydrogen atom,

$-(2.18 \times 10^{-18}$ J) Z^2 $(\frac{1}{\infty^2} - \frac{1}{2^2})$

Hence H (Z=1),

$-(2.18 \times 10^{-18}$ J) $(\frac{1}{4})$ = **5.45 X 10⁻¹⁹ J**

(b) (2 pts)

For 1s electron of He$^+$ ion

He$^+$ (Z=2) : 2.18×10^{-18} J (Z^2) = 4 X 2.18×10^{-18} J = **8.72 X 10⁻¹⁸ J**

(c) (4 pts) for each limit, 2 pts

Helium has two $1S^2$ electrons,

attracted to a nucleus containing two protons (Z=2)

Competing for the same nuclear charge, the electrons screen one another.

   Lower limit : Each 1s electron screens the other completely.

           Effective nuclear charge Z_{eff} = 2-1=1

   Upper limit : No screening at all.

           Each electron interacts with the full nuclear charge

           so are to make Z_{eff}= 2

Heliums' first ionization energy thus falls between 2.18×10^{-18} J X (1^2)

and 2.18×10^{-18} J X (2^2)

  lower limit : 2.18 X 10⁻¹⁸ J

  upper limit : 8.72 X 10⁻¹⁸ J

7. (total 11 pts)

(a) (6 pts) proof 3 pts; energy eigenvalue 3 pts

Note that $h = \hbar = h/2\pi$.

$$-\frac{\hbar^2}{2m_e}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)\psi = -\frac{\hbar^2}{2m_e}\frac{1}{r^2}\frac{\partial}{\partial r}r^2\left(1-\frac{r}{2a}\right)e^{-r/2a}\sin\theta\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2-\frac{r^3}{2a}\right)e^{-r/2a}\sin\theta\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\frac{1}{r^2}\left[\left(2r-\frac{3r^2}{2a}\right)-\frac{1}{2a}\left(r^2-\frac{r^3}{2a}\right)\right]e^{-r/2a}\sin\theta\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\frac{1}{r}\left(2-\frac{2r}{a}+\frac{r^2}{4a^2}\right)e^{-r/2a}\sin\theta\cos\phi$$

$$-\frac{\hbar^2}{2m_e}\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right)\psi = -\frac{\hbar^2}{2m_e}\frac{1}{r^2\sin\theta}re^{-r/2a}\frac{\partial}{\partial\theta}\left(\sin\theta\cos\theta\right)\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\frac{1}{r\sin\theta}e^{-r/2a}\left(\cos^2\theta-\sin^2\theta\right)\cos\phi$$

$$-\frac{\hbar^2}{2m_e}\frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\phi^2}\psi = +\frac{\hbar^2}{2m_e}\frac{1}{r^2\sin^2\theta}re^{-r/2a}\sin\theta\cos\phi$$

$$=\frac{\hbar^2}{2m_e}\frac{1}{r\sin\theta}e^{-r/2a}\cos\phi$$

By combining the above three, the term in the large bracket in the Schrödinger equation is:

$$-\frac{\hbar^2}{2m_e}\left[\frac{1}{r}\left(2-\frac{2r}{a}+\frac{r^2}{4a^2}\right)\sin\theta+\frac{1}{r\sin\theta}\left(\cos^2\theta-\sin^2\theta\right)-\frac{1}{r\sin\theta}\right]e^{-r/2a}\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\frac{1}{r\sin\theta}\left[\left(2-\frac{2r}{a}+\frac{r^2}{4a^2}\right)\sin^2\theta+\left(\cos^2\theta-\sin^2\theta\right)-1\right]e^{-r/2a}\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\frac{1}{r\sin\theta}\left[\left(2-\frac{2r}{a}+\frac{r^2}{4a^2}\right)\sin^2\theta+\left(1-\sin^2\theta-\sin^2\theta\right)-1\right]e^{-r/2a}\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\frac{1}{r\sin\theta}\left[\left(-\frac{2r}{a}+\frac{r^2}{4a^2}\right)\sin^2\theta\right]e^{-r/2a}\cos\phi$$

$$=-\frac{\hbar^2}{2m_e}\left(-\frac{2}{a}+\frac{r}{4a^2}\right)e^{-r/2a}\sin\theta\cos\phi$$

Then, by using $\hbar^2/(m_e a)=e^2/(4\pi\varepsilon_0)$, the last term of the left hand side becomes:

$$-\frac{\hbar^2}{m_e a}\frac{1}{r}re^{-r/2a}\sin\theta\cos\phi=-\frac{\hbar^2}{2m_e}\frac{2}{a}e^{-r/2a}\sin\theta\cos\phi$$

Therefore, the whole left term becomes:

$$-\frac{\hbar^2}{2m_e}\left(-\frac{2}{a}+\frac{r}{4a^2}\right)e^{-r/2a}\sin\theta\cos\phi-\frac{\hbar^2}{2m_e}\frac{2}{a}e^{-r/2a}\sin\theta\cos\phi$$

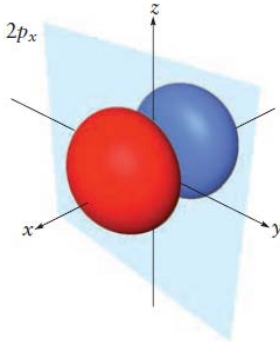$$=-\frac{\hbar^2}{8m_e a^2}re^{-r/2a}\sin\theta\cos\phi$$

$$=-\frac{\hbar^2}{8m_e a^2}\psi$$

Thus, $E = -\dfrac{h^2}{8m_e a^2} = -\dfrac{h^2}{8m_e}\left(\dfrac{e^4 m_e^2}{16\pi^2 \varepsilon_0^2 h^4}\right) = -\dfrac{e^4 m_e}{32\varepsilon_0^2 h^2} = -5.45\times10^{-19}\,\text{J} = -3.40\,\text{eV}$

(b) (2 pts)

$\psi = 0$ only when $r = 0$, namely at the nucleus. Thus, there is no radial node.

(c) (3 pts)

The function is positively (negatively) large when $\phi = 0$ ($\phi = \pi$) with an angular node at $\phi = \pi/2$.

It also is large at $\theta = \pi/2$ but zero at $\theta = 0$ and $\theta = \pi$.

8. (total 11 pts)

(a) (2 pts)

$1s^2\, 2s^2\, 2p^6$

(b) (3 pts) for each, 1 pt

Energy of the injected light: E = hc/λ = (6.626*10^-34 Js) * (3.0*10^8 m/s) / (9.89*10^-10 m)

= 2.0085 x 10^-16 J = 1253.6 eV

IE_1 = 1253.6 − 384.4 = 870.2 eV ➜ 1s orbital

IE_2 = 1253.6 − 1205.2 = 48.4 eV ➜ 2s orbital

IE_3 = 1253.6 − 1232.0 = 21.6 eV ➜ 2p orbital

(c) (6 pts) for each, 2 pts

From the Koopman's approximation, we can calculate the orbital energy. [ϵ_n(orb) = − IE_n]

ϵ(orb) = -Z_{eff}/n², Z_{eff} = $\sqrt{n^2(-\epsilon)}$, where ϵ is in Rydberg.

Since 1 Rydberg = 2.18 x 10⁻¹⁸ J and 1 eV = 1.602 x 10⁻¹⁹ J, we can calculate the Z_{eff} of each orbital.

$Z_{eff}(1s) = \sqrt{1^2\,\dfrac{-(-870.2\ eV)}{13.6\ eV/Ryd}} = 8.00$

$Z_{eff}(2s) = \sqrt{2^2\,\dfrac{-(-48.4\ eV)}{13.6\ eV/Ryd}} = 3.77$

$Z_{eff}(2p) = \sqrt{2^2\,\dfrac{-(-21.6\ eV)}{13.6\ eV/Ryd}} = 2.52$

9. (total 12 pts)

(a) (3 pts)

Due to the odd number of valence electrons (5 for N + 6 for O = 11), it is **paramagnetic**.

(b) (6 pts) 2s 1 pt; 2p 1 pt; the sequence of pi and sigma 2 pts; electron 2 pts
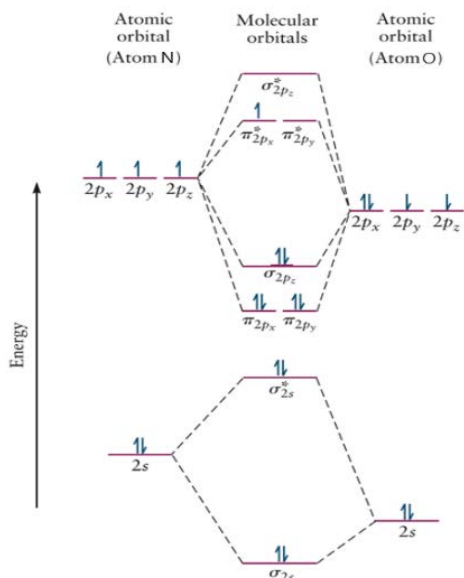
(c) (3 pts)

The highest occupied molecular orbital is π_{2p}^*.

Its shape is:
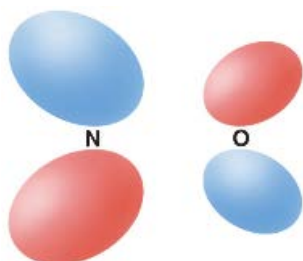
The lobe size must be larger for N atom and the lobe color blue and red indicate + and - sign (or *vice versa*), respectively.

10. (total 11 pts)

(a) (3 pts) structure 1 pt; sp & sp^2 2 pts

(b) (4 pts) sigma 1 pt; pi 1 pt; perpendicular between pi bonds 2 pts

(c) (4 pts) orbital diagram & label 2 pts; sketch of the orbitals 2 pts

2018 SPRING Semester Final Examination
For General Chemistry I

Date: June 18 (Mon),   Time Limit: 19:00 ~ 21:00

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

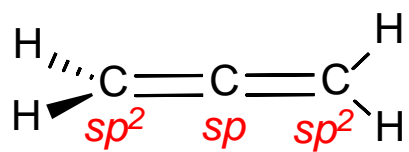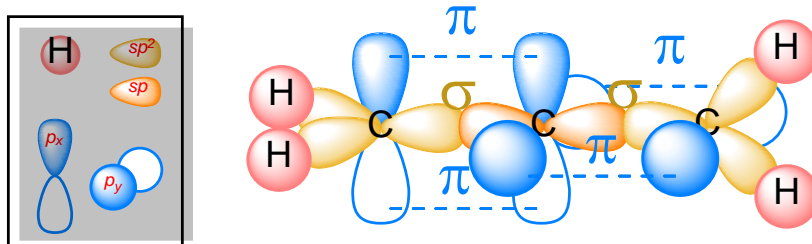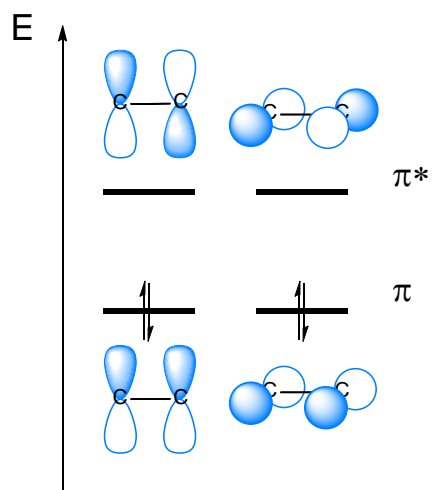| Prof. Name	Class	Student I.D. Number	Name	
Problem	points	Problem	points	TOTAL pts
1	/6	**7**	/9	
2	/7	**8**	/7	
3	/9	**9**	/7	
4	/6	**10**	/9	**/100**
5	/12	**11**	/10	
6	/10	**12**	/8	

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

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

NOTICE: SCHEDULES on RETURN and CLAIM of the MARKED EXAM PAPER.
(채점 답안지 분배 및 이의신청 일정)

 1. Period, Location, and Procedure

   1)   Return and Claim Period: *June 20 (Wed, 15: 00 ~ 17:00 p.m.)*

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

Class	Room	Class	Room	Class	Room
A	*203*	*D*	*207*	*G*	*211*
B	*205*	*E*	*208*		
C	*206*	*F*	*210*		

   3)   Procedure:

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

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

(During the period, you can check the marked exam paper from your TA and should hand in the paper with a FORM for claims if you have any claims on it. The claim is permitted only on the period. Keep that in mind! A solution file with answers will be uploaded on **June 20** on the web.)

2. Final Confirmation

   1) Period: June 21 (Thu)

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

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

1. (Total 6 pts)

(a) The air over an unknown liquid is saturated with the vapor of that liquid at 25 °C and a total pressure of 0.980 atm. Suppose that a sample of 6.00 L of the saturated air is collected and the vapor of the unknown liquid is removed from that sample by cooling and condensation. The pure air remaining occupies a volume of 3.75 L at -50 °C and 1.000 atm. Calculate <u>the vapor pressure</u> of the unknown liquid at 25 °C.

(Answer)

(b) Among the seven species below, <u>choose two species</u> whose boiling points are the closest to that of the unknown species above.
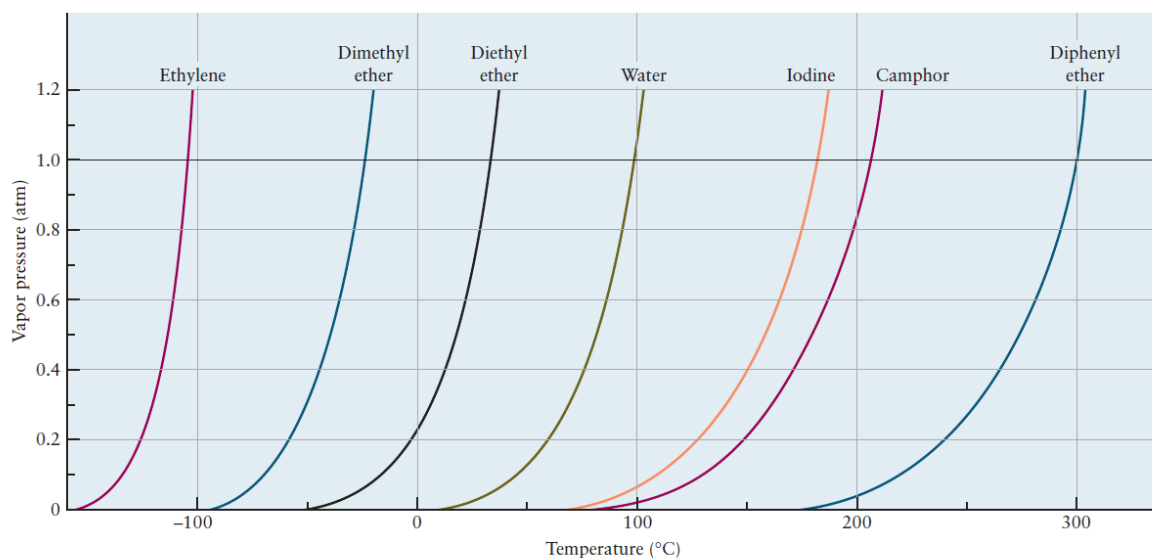
FIGURE 10.17 The vapor pressure of a solid or liquid depends strongly on temperature. The temperature at which the vapor pressure becomes 1 atm defines the normal boiling point of a liquid and the normal sublimation point of a solid.

(Answer)

2. (Total 7 pts)

(a) <u>Arrange</u> the following substances <u>in order of decreasing</u> critical temperature (T_c) :

   Ar, H_2, Kr, CCl_3F

(Answer)

(b) Which of the following substances should we expect to have <u>the lower vapor pressure</u> at a given temperature :

(1) CO_2 or SO_2

(Answer)

(2) CH_3OCH_3 or CH_3CH_2OH

(Answer)

3. (Total 9 pts)

(a) <u>Balance the following reaction</u> that takes place in basic solution.

$$Cr(OH)_3(s) + Br_2(aq) \rightarrow CrO_4^{2-}(aq) + Br^-(aq)$$
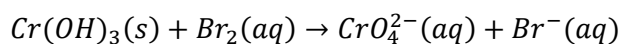
(Answer)

(b) 103.0 g Cr(OH)$_3$ solid powder is added to the solution that contains 0.3 mol Br$_2$ and 2 mol NaOH dissolved in 1 kg water. Estimate <u>the freezing point of the solution</u> after the reaction is completed, assuming K_f = 1.86 K·kg·mol^{-1}. (Atomic mass: H, 1.008; O, 15.999; Na, 22.990; Cr, 51.996; Br, 79.904).

(Answer)

4. (Total 6 pts)

(a) At its melting point (624 °C) at 1 atm, the density of solid plutonium is 16.24 g/cm^3 while the density of the liquid is 16.66 g/cm^3. Predict <u>what phase changes</u>, if any, will occur when a small sample of liquid plutonium at 625 °C is strongly compressed isothermally.

(Answer)

(b) If the phase diagram is drawn for plutonium at the liquid-solid boundary around 1 atm and 624 °C, what will <u>it look like</u>?

(1)
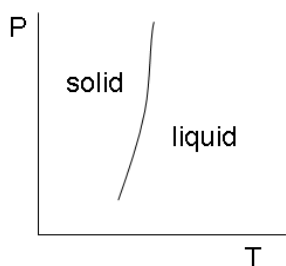
(2)
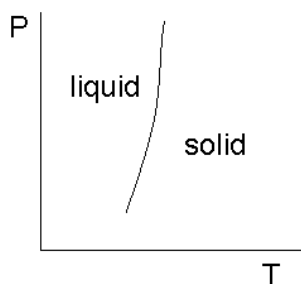
(3)
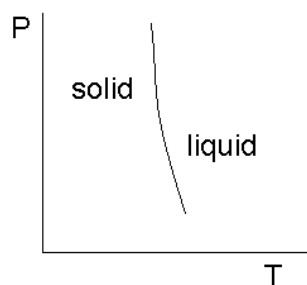
(4)
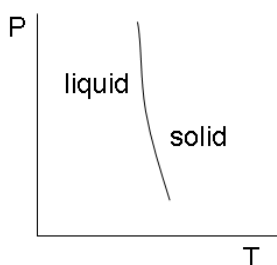
Give <u>a reasoning</u> for your answer as briefly as possible.

(Answer)

5. (Total 12 pts) One mole of liquid water is allowed to equilibrate with its vapor inside a one-liter vessel. The vapor pressure at 20 ℃ is then found to be 17.5 torr.

(a) <u>How many moles</u> of water exist in the vapor state? Assume ideal behavior.
(Answer)

(b) Suppose that the volume of the vessel is doubled to 2L. What is <u>the new vapor pressure</u>?
(Answer)

(c) <u>How many moles</u> of water vapor are present in the larger container?
(Answer)

(d) Water's vapor pressure falls from 17.5 torr at 20 ℃ to 9.2 torr at 10 ℃. If equilibrium is first established at 20 ℃ in a volume of 1 L, then approximately <u>how many mL of water</u> will condense when the temperature is lowered to 10 ℃? Assume that liquid water has a density of 1 g/mL.

(Answer)

(e) The vapor pressure of water/ sucrose solution ($C_{11}H_{22}O_{11}$, table sugar) is found to be 16.1 torr at 20 ℃, lower by 1.4 torr compared with pure water. The solution, presumed to be ideal, contains 500 g of water. Compute <u>the molality</u>.
(Answer)

6. (Total 10 pts) A sample of pure solid naphthalene ($C_{10}H_8$) weighing 0.6410 g is burned completely with oxygen to $CO_2(g)$ and $H_2O(l)$ in a constant-volume calorimeter at 25°C. The amount of heat evolved is observed to be 25.79 kJ. (the M_w of $C_{10}H_8$ is 128.17g/mol, R = 8.3145J K^{-1} mol^{-1})

(a) Write and <u>balance the chemical equation</u> for the combustion reaction.

(Answer)

(b) Calculate <u>the standard change in internal energy</u> ($\Delta U°$) for the combustion of 1.000 mol naphthalene to $CO_2(g)$ and $H_2O(l)$.

(Answer)

(c) Calculate <u>the standard enthalpy change</u> ($\Delta H°$) for the same reaction as in part (b).

(Answer)

7. (Total 9 pts) Suppose 2.00 mol of a monatomic ideal gas is initially at a pressure of 3.00 atm and a temperature $T = 350$ K. It is expanded irreversibly and adiabatically ($q = 0$) against a constant external pressure of 1.00 atm until the volume has doubled.

(a) Calculate <u>the final volume</u>.

(Answer)

(b) Calculate <u>w and ΔU</u> for this process, in joules.

(Answer)

(c) Calculate <u>the final temperature</u> of the gas.

(Answer)

8. (Total 7 pts)

(a) Calculate <u>the entropy of crystal</u> made of 1 mol carbon monoxide (CO) at T = 0K when CO molecules are in random, but parallel arrangement.

(Answer)

(b) Dichloromethane (CH_2Cl_2) is one of the methane (CH_4) derivatives. If 1 mol of CH_2Cl_2 adopts a random arrangement in its crystal form, what would be <u>its entropy value at T = 0K</u>?

(Answer)

9. (Total 7 pts) Calculate <u>ΔS_{sys}, ΔS_{surr}, and ΔS_{tot}</u> for the irreversible isothermal expansion at 298 K of 5.00 mol of an ideal gas from a pressure of 10.0 atm to constantly held external pressure of 1.00 atm.

(Answer)

10. (Total 9 pts) For the reaction equilibrium,

$$4\ NH_3\ (g) + 7\ O_2\ (g) \leftrightharpoons 4\ NO_2\ (g) + 6\ H_2O\ (g)$$
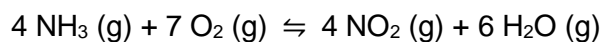
(a) Calculate $\Delta G°$ and the equilibrium constant K at 25°C for the reaction with the standard free energies of formations, $\Delta G_f°$, in kJ/mol: H_2O, -228.59; NH_3, -16.48; NO_2, 51.29.

(Answer)

(b) Calculate $\Delta G°$ and the equilibrium constant K at 0 °C for the reaction with the standard enthalpy of formations, $\Delta H_f°$, in kJ/mol: H_2O, -241.82; NH_3, -46.11; NO_2, 33.18. Assume that standard reaction enthalpy ($\Delta H°$) and entropy ($\Delta S°$) do not change at different temperatures.

(Answer)

(c) Calculate the standard entropy of O_2 at 25°C given with the other standard entropies at the same temperature in J/K·mol: H_2O, 188.72; NH_3, 192.34; NO_2, 239.95.

(Answer)

11. (Total 10 pts) Explain <u>the effect</u> of each of the following stresses <u>(from right to left, from left to right, or no effect)</u> on the position of the following equilibrium:

$$3NO(g) \rightleftharpoons N_2O(g) + NO_2(g)$$
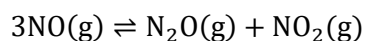
The reaction as written is exothermic.

(a) $N_2O(g)$ is added to the equilibrium mixture without change of volume or temperature.
(Answer)

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

(c) The equilibrium mixture is cooled.
(Answer)

(d) Gaseous argon (which does not react) is added to the equilibrium mixture while both the total gas pressure and the temperature are kept constant.
(Answer)

(e) Gaseous argon is added to the equilibrium mixture without changing the volume.
(Answer)

12. (Total 8 pts) Below equation is Van't Hoff equation, which explains the relationship between temperature and equilibrium constants.

$$\ln\left(\frac{K_2}{K_1}\right) = -\frac{\Delta H°}{R}\ \left[\ \frac{1}{T_2} - \frac{1}{T_1}\ \right]$$

(a) Calculate <u>the equilibrium constant</u> of next reaction at standard condition. Is the reaction at this condition <u>forward favored or backward favored</u>?

$$CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g),\ \Delta G°_{reaction} = 113.63\ kJ/mol$$
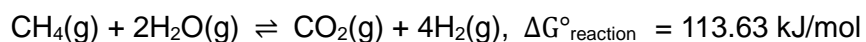
(Answer)

(b) Compute <u>the new equilibrium constant</u> when the reaction temperature was elevated to 1000 K. Use next value of given table. Is the new equilibrium <u>forward favored or backward favored</u>?

	$CH_4(g)$	$H_2O(g)$	$CO_2(g)$	$H_2(g)$
$\Delta H°_{formation}$ (kJ mol^{-1})	−74.9	−241.8	−393.5	0

(Answer)

Physical Constants

Avogadro's number	$N_A = 6.02214179 \times 10^{23} \text{ mol}^{-1}$
Bohr radius	$a_0 = 0.52917720859 \text{ Å} = 5.2917720859 \times 10^{-11} \text{ m}$
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	$\varepsilon_o = 8.854187817 \times 10^{-12} \text{ C}^{-2} \text{ J}^{-1} \text{ m}^{-1}$
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	$1 \text{ Å} = 10^{-10} \text{ m}$
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

KEY

79	Atomic number
Au	Symbol
Gold	Name
196.9665	Atomic weight

An element

- Main group metals
- Transition metals
- Metalloids
- Nonmetals, noble gases

Period number — 1

Group number, U.S. system — 1A (1)
Group number, IUPAC system — (1)

Numbers in parentheses are mass numbers of radioactive isotopes.

Period	1A (1)	2A (2)		3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 **H** Hydrogen 1.0079																		2 **He** Helium 4.0026
2	3 **Li** Lithium 6.941	4 **Be** Beryllium 9.0122												5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.0067	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984	10 **Ne** Neon 20.1797
3	11 **Na** Sodium 22.9898	12 **Mg** Magnesium 24.3050												13 **Al** Aluminum 26.9815	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.9738	16 **S** Sulfur 32.065	17 **Cl** Chlorine 35.453	18 **Ar** Argon 39.948
4	19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078		21 **Sc** Scandium 44.9559	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.9380	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.9332	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.64	33 **As** Arsenic 74.9216	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.798
5	37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62		39 **Y** Yttrium 88.9058	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.9064	42 **Mo** Molybdenum 95.96	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.9055	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.9045	54 **Xe** Xenon 131.293
6	55 **Cs** Cesium 132.9055	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.084	79 **Au** Gold 196.9666	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.9804	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
7	87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (267)	105 **Db** Dubnium (268)	106 **Sg** Seaborgium (271)	107 **Bh** Bohrium (272)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (276)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (280)	112 — (285)	113 — (284)	114 — (287)	115 — (288)	116 — (293)		118 — (294)

Lanthanides 6	58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.9076	60 **Nd** Neodymium 144.242	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.9254	66 **Dy** Dysprosium 162.500	67 **Ho** Holmium 164.9303	68 **Er** Erbium 167.259	69 **Tm** Thulium 168.9342	70 **Yb** Ytterbium 173.054	71 **Lu** Lutetium 174.9668
Actinides 7	90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.0359	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

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Claim Form for General Chemistry Examination

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		Accepted?　Yes(√) or No(√)	
Question #	Claims	Yes: ☐	No: ☐
		Pts (+/-)	Reasons

sheet if you need more before use.

\<The Answers\>

Problem	points	Problem	points	TOTAL pts
1	4+2/6	**7**	3+3+3/9	
2	3+4/7	**8**	3+4/7	
3	3+6/9	**9**	3+3+1/7	
4	3+3/6	**10**	3+3+3/9	**/100**
5	2x3+3+3/12	**11**	2x5/10	
6	3+3+4/10	**12**	4+4/8	

Missing units in the answer: -1 pt, "-1 pt" means "minus 1 point"

1. (Total 6 pts)

(a) (4 pts) P_{air} 2 pts, $P_{unknown}$ 2 pts
The chemical amount of air that was present in the 6.00 L portion of air mixed with the vapors of the unknown can be computed because its physical state after purification is fully described. Assuming ideality

$$n_{air} = \frac{PV}{RT} = \frac{(1.000 \text{ atm})(3.75 \text{ L})}{(0.08206 \text{ L atm mol}^{-1}\text{K}^{-1})(223.15 \text{ K})} = 0.2048 \text{ mol}$$

$$P_{air} = \frac{n_{air}RT}{V}$$

$$P_{air} = \frac{(0.2048 \text{ mol})(0.08206 \text{ L atm mol}^{-1}\text{K}^{-1})(298.15 \text{ K})}{6.00 \text{ L}} = 0.835 \text{ atm}$$

But the total pressure above the unknown was 0.980 atm. By Dalton's law

$$P_{unknown} = 0.980 - 0.835 = 0.145 \text{ atm}$$

(b) (2 pts) each liquid 1 pt
The unknown liquid has a vapor pressure of 0.145 atm at 25 °C. Thus its vapor pressure curve lies between those of water and diethyl ether. Therefore, **water and diethyl ether** have the boiling points closest to the unknown liquid.

2. (Total 7 pts)

(a) (3 pts)
CCl_3F is a polar molecule (strong dipole-dipole forces)
We expect that CCl_3F will have the highest T_c.
The remaining 3 substances can interact only by way of induced dipole-dipole (London dispersion force)
We would predict T_c to decrease in the order Kr(36 electrons), Ar(18 electrons), and H_2(2 electrons).

(b) (4 pts) each 2 pts
(1) London forces between SO_2 molecules should be greater than CO_2.
Moreover, as SO_2 is polar but CO_2 is not.
Therefore SO_2 has the lower vapor pressure.

(2) Molecular weights are equal.
However, there will be strong hydrogen bonding in ethanol.
We expect ethanol to have the lower vapor pressure.

3. (Total 9 pts)

(a) (3 pts)
$10\ OH^-$ (aq) + 2 $Cr(OH)_3$ (s) + 3 Br_2 (aq) → 2 CrO_4^{2-} (aq) + 6 Br^- (aq) + 8 H_2O (l)
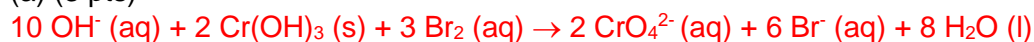
(b) (6 pts) mole change 2 pts, total water mass 1 pt, freezing point depression 3 pts
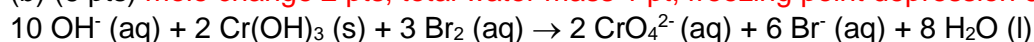
$10\ OH^-$ (aq)	+ 2 $Cr(OH)_3$ (s)	+ 3 Br_2 (aq)	→ 2 CrO_4^{2-} (aq)	+ 6 Br^- (aq)	+ 8 H_2O (l)
2 mol	1 mol	0.3 mol			
-1 mol	-0.2 mol	-0.3 mol	+0.2 mol	+0.6 mol	+0.8 mol
1 mol	0.8 mol	0 mol	0.2 mol	0.6 mol	0.8 mol

After the reaction, 2 mol Na^+(aq) + 1 mol OH^-(aq) + 0.2 mol CrO_4^{2-} (aq) + 0.6 mol Br^-(aq) = 3.8 moles of solute are left in the aqueous phase. Total water mass is 1 kg + (0.8 mol)*(15.999+1.008*2 g/mol)*(1/1000 kg/g) = 1.014 kg.
Use these to calculate the freezing point depression of
$\Delta T_f = -K_f*m = -(1.86\ K \cdot kg \cdot mol^{-1})*(3.8\ mol/1.014\ kg) = -6.97\ K$
Thus, the freezing point of this solution mixture after the reaction is **-6.97 °C**.

4. (Total 6 pts)

(a) (3 pts)
At 624 °C, both liquid and solid are at equilibrium and the liquid is denser. Therefore, when it is compressed at the same temperature, the equilibrium will shift to the denser side and the solid will melt. Namely, the melting point lowers. At 625 °C (above melting point), plutonium will exist as liquid, and as it gets compressed, the melting point will lower. Thus, because the maintained temperature will be higher than the melting temperature and the sample will remain in the liquid state. (No change will happen.)

(b) (3 pts)
At lower temperature: solid → either (1) or (3); melting point lowers at higher pressure → (3) or (4).
Therefore, (3) is the right shape.

5. (Total 12 pts)

(a) (2 pts)

$P = 17.5 \text{ torr} \times \dfrac{1 \text{ atm}}{760 \text{ torr}} = 0.023 \text{ atm}$

$V = 1L$, $T = 20°C = 293 \text{ K}$, $R = 0.082 \text{ atm L mol}^{-1} \text{ K}^{-1}$

$n = \dfrac{PV}{RT} = \underline{9.57 \times 10^{-4} \text{ mol}}$

(b) (2 pts)

The same as in a 1L container: <u>17.5 torr</u>
The vapor pressure depends only on temperature.

(c) (2 pts)

Since the volume doubles, so must the number of moles.

9.57×10^{-4} moles $\times 2 = \underline{1.91 \times 10^{-3} \text{mol}}$

(d) (3 pts)

$P = 9.2 \text{ torr} \times \dfrac{1 \text{ atm}}{760 \text{ torr}} = 0.012 \text{ atm}$

$V = 1L$, $T = 10°C = 283 \text{ K}$

$n = \dfrac{PV}{RT} = \dfrac{0.012 \times 1}{0.082 \times 283} = 5.2 \times 10^{-4} \text{ mol}$

$9.57 \times 10^{-4} \text{ mol} - 5.2 \times 10^{-4} \text{ mol} = 4.4 \times 10^{-4} \text{ mol}$

The difference, 4.4×10^{-4} mol, condensate

$4.4 \times 10^{-4} \text{ mol} \times \dfrac{18g}{\text{mol}} \times \dfrac{1mL}{1g} = \underline{7.9 \times 10^{-3} \text{mL}}$

(e) (3 pts)

$n_1 = 500g \ H_2O \times \dfrac{1 \text{ mol}}{18g} = 27.8 \text{ mol } H_2O$

$X_1 = \dfrac{n_1}{n_1 + n_2} \qquad X_1(n_1 + n_2) = n_1$

$n_2 = \dfrac{n_1(1 - X_1)}{X_1}$

$P_1 = X_1 P_1^{\ 0}$

$X_1 = \dfrac{P_1}{P_1^{\ 0}} = \dfrac{16.1 \text{ torr}}{17.5 \text{ torr}} = 0.92$

$n_2 = \dfrac{n_1(1 - X_1)}{X_1} = \dfrac{(27.8)(1 - 0.92)}{0.92} = 2.47 \text{ mol}$

$\text{molality} = \dfrac{2.417 \text{mol sucrose}}{0.5 \text{kg } H_2O} = \underline{4.83 \text{ m}}$

6. (Total 10 pts)

(a) (3 pts)

a) The equation is $\boxed{C_{10}H_8(s) + 12\,O_2(g) \longrightarrow 10\,CO_2(g) + 4\,H_2O(l)}$.

(b) (3 pts)

b) The amount of heat evolved $(-q)$ in the combustion of 0.6410 g of naphthalene was observed to equal 25.79 kJ. Since the combustion was performed at constant volume, no work was done on the system $(w = 0)$. Therefore, $\Delta U = q + w = -25.79\text{ kJ} + 0 = -25.79\text{ kJ}$. Put this ΔU on a molar basis to correspond to the 1 mol of naphthalene appearing in the balanced equation

$$\Delta U = \left(\frac{-25.79 \text{ kJ}}{0.6410 \text{ g } C_{10}H_8} \right) \times \left(\frac{128.17 \text{ g } C_{10}H_8}{1 \text{ mol } C_{10}H_8} \right) = -5157 \text{ kJ mol}^{-1}$$

The temperature is 25°C both before and after the reaction. Therefore for the equation written above (which shows 1 mol of naphthalene) $\Delta U^\circ = \boxed{-5157 \text{ kJ}}$.

(c) (4 pts)

c) To calculate ΔH° use the definition

$$\Delta H^\circ = \Delta U^\circ + \Delta(PV)$$

Assume that the gases are ideal and that the volumes of the solids are negligible. Then $\Delta(PV) = (\Delta n_g)RT$, and

$$\Delta H^\circ = \Delta U^\circ + (\Delta n_g)RT$$

The Δn_g is the change in the number of moles of gases during the reaction. The combustion of 1 mol of naphthalene produces 10 mol of gas, while consuming 12 mol of gas. Accordingly

$$(\Delta n_g)RT = (-2 \text{ mol})(8.3145 \text{ J K}^{-1}\text{mol}^{-1})(298.15 \text{ K}) = -4.96 \text{ kJ}$$

$$\Delta H^\circ = \Delta U^\circ + (\Delta n_g)RT = -5157 \text{ kJ} - 4.96 \text{ kJ} = \boxed{-5162 \text{ kJ}}$$

7. (Total 9 pts)

(a) (3 pts)

Initially, n = 2.00 mol, P_0 = 3.00 atm, T_0 = 350 K. Thus, V_0 = nRT/P = 19.1 L.
After expansion, V = $2V_0$ = 38.3 L.

(b) (3 pts)

w = -P_{ext} ΔV = -1.00 atm * 19.1 L = -101325 Pa * 0.0191 m^3 = -1940 J.
Because the process is adiabatic, ΔU = w = -1940 J.

(c) (3 pts)

For monatomic ideal gas, $\Delta U = \dfrac{3}{2}nR\Delta T$. Therefore, ΔT = -77.8 K, and the final temperature is 272 K.

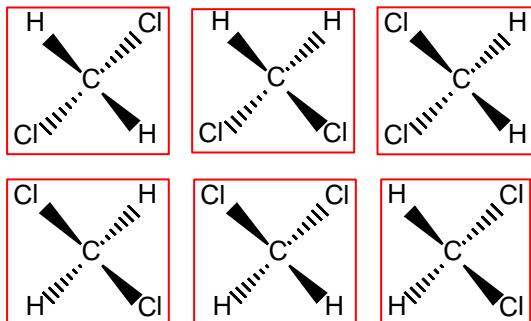**8. (Total 7 pts)**

(a) (3 pts)
$S = k_B \ln 2^{N_A} = k_B N_A \ln 2 = 5.76$ J/K

(b) (4 pts) 6 orientations 2 pts; entropy 2 pts
There are six orientations of CH_2Cl_2 molecule as shown below:

$S = k_B \ln 6^{N_A} = k_B N_A \ln 6 = 14.90$ J/K

9. (Total 7 pts) ΔS_{sys} 3 pts, ΔS_{surr} 3 pts, ΔS_{tot} 1 pt

$\Delta S_{tot} = \Delta S_{sys} + \Delta S_{surr}$
Since S is a function of state, ΔS_{sys} for the irreversible process is equal to ΔS_{sys} for the reversible process with the same initial and final states.
Thus, $\Delta S_{sys} = q_{rev}/T = -w/T = -[-nRT \ln (V_2/V_1)]/T = -[-nRT \ln (P_1/P_2)]/T = nR \ln (P_1/P_2)$
$= (5.00 \text{ mol})(8.315 \text{ J K}^{-1} \text{ mol}^{-1}) \ln (10.0 \text{ atm}/1.00 \text{ atm})$
$= 95.7$ J K^{-1}

$\Delta S_{surr} = $ (heat given up by the surrounding)/T = -(heat absorbed by the system)/T
$= -q_{irrev}/T = -(-w_{irrev})/T = (w_{irrev})/T = -P_{ext}\Delta V/T = -(1 \text{ atm})(V_f-V_i)/T$
$V_i = nRT/P_i = (5.00 \text{ mol})(0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1})(298 \text{ K})/10.0 \text{ atm} = 12.2$ L
$V_f = nRT/P_f = (5.00 \text{ mol})(0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1})(298 \text{ K})/1.00 \text{ atm} = 122$ L
Thus,
$\Delta S_{surr} = -(1 \text{ atm})(V_f-V_i)/T = - (1 \text{ atm})(122 \text{ L} - 12.2 \text{ L})/298 \text{ K} = - (109.8 \text{ L atm})/298 \text{ K}$
$= - (109.8 \text{ L atm})(101.3 \text{ J}/1 \text{ L atm}) /298 \text{ K} = - 37.3$ J K^{-1}

Hence, $\Delta S_{tot} = \Delta S_{sys} + \Delta S_{surr} = 95.7 \text{ J K}^{-1} + (- 37.3 \text{ J K}^{-1}) = 58.4$ J K^{-1}

10. (Total 9 pts)

(a) (3 pts)

$\Delta G°$/(kJ/mol) = 4 * 51.29 + 6 * (-228.59) − 4 * (-16.48) − 7 * 0 = -1100.46

From $\Delta G = \Delta G° + RT° \ln Q = 0$, when Q = K, we get

$$K = \exp\left(-\frac{\Delta G°}{RT°}\right) = 6._2 \times 10^{192}.$$

(b) (3 pts)

At 25°C,

$\Delta H°$/(kJ/mol) = 4 * 33.18 + 6 * (-241.82) − 4 * (-46.11) − 7 * 0 = -1133.76

$$\Delta S° = -\frac{\Delta G° - \Delta H°}{T°} = -111.7 \text{ J/mol} \cdot \text{K}$$

Therefore, at T = 273.15 K,

$$\Delta G° = \Delta H° - T\Delta S° = -1103.25 \text{ kJ/mol}$$

$$K = \exp\left(-\frac{\Delta G°}{RT}\right) = 9._3 \times 10^{210}.$$

(c) (3 pts)

$\Delta S°$/(J/K·mol) = 4 * 239.95 + 6 * 188.72 − 4 * 192.34 − 7 x = -111.7

Therefore, x = 204.9 and the standard entropy is 204.9 J/K·mol.

* exp(443.9) = exp(192.8 * ln 10) = (exp (ln 10))^192.8 = 10^192.8 = 10^0.8 * 10^192
   = 6.3 * 10^192

11. (Total 10 pts) for each, 2 pts

Chemical systems always tend toward equilibrium.[2] If a stress is applied to a system at equilibrium, the system reacts to minimize the stress and to reach a new equilibrium.

a) The stress is the addition of $N_2O(g)$. The system reacts to decrease the concentration of N_2O. The reaction proceeds from right to left until a new equilibrium is reached.

b) 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 (chemical amount of gas) in the container and reduce the total pressure. There are three moles of gas on the reactant side of the equation and two moles of gas on the product side. The equilibrium will thus shift from left to right.

c) The reaction is exothermic. Cooling the mixture shifts the equilibrium from left to right (to favor the products).

d) In order to maintain a constant pressure, the volume of the system must have increased. Thus, the reaction will shift from right to left.

e) The partial pressures of the reacting gases are unchanged by the addition of an inert gas, and the equilibrium law is independent of total pressure. There is no effect on the position of the equilibrium.

12. (Total 8 pts)

(a) (4 pts) K 3 pts, backward 1 pt

$\ln K = -\Delta G°/RT$ = - 113.63 x 1000 J mol^{-1} / (8.314 J K^{-1} mol^{-1} x 298 K) = - 45.86

∴ K = 1.21 x 10^{-20}

Because Equilibrium constant is smaller than one, it is backward favored at 298K.

(b) (4 pts) K 3 pts, forward 1 pt

Let equilibrium constant K_1 for 25 °C(298K), and K_2 for 1000K

$\Delta H°_{reaction} = \Delta H°_{formtaion}(\text{product}) - \Delta H°_{formtaion}(\text{reactant})$

 = [(- 393.5 kJ/mol) x 1mol + (0 kJ/mol) x 3mol)] – [(-74.9 kJ/mol) x 1mol + (-241.8 kJ/mol) x 2mol]

 = 165 kJ

Let the reaction is proceeded for 1mol CO_2 (g). Then $\Delta H°_{reaction}$ can be considered as 165 kJ/mol.

$\ln\left(\dfrac{K_2}{K_1}\right) = -\dfrac{\Delta H°}{R} \left[\dfrac{1}{T_1} - \dfrac{1}{T_2}\right] = -\dfrac{165 \text{ kJ/mol}}{8.314 \text{ J/K mol}} \left[\dfrac{1}{1000 \text{ K}} - \dfrac{1}{298 \text{ K}}\right]$ = 46.75

∴ $K_2 = K_1$ x $e^{46.75}$ = 2.4324

New equilibrium constant is larger than one. Therefore, it is forward favored at 1000K.