Chemistry I Final Exam

18:00-21:00, 8 January, 2016 (Total Score: 106 points)

1 1A												13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 H 1.008	2 2A																2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 *La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 †Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (268)	110 Ds (271)	111 Rg (280)	112 Uub		114 Uuq		116 Uuh		118 Uuo

*Lanthanide series	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (147)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
†Actinide series	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np 237.0	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

gas constant $R = 8.314\ J\cdot mol^{-1}\cdot K^{-1} = 8.206\times10^{-2}\ L\cdot atm\cdot mol^{-1}\cdot K^{-1} = 8.314\times10^{-2}\ L\cdot bar\cdot mol^{-1}\cdot K^{-1}$

Boltzmann's constant $k_B = 1.38\times10^{-23}\ L\cdot atm\cdot K^{-1}$

Part I. True (T) or false (F), 1% each

1. The liquid and gas phases of a substance become indistinguishable when $T > T_c$ and $P > P_c$. (The subscript "c" means critical)
2. There is only one triple point in the phase diagram of H_2O.
3. For a pure substance, it is impossible to find a condition under which four phases can be in equilibrium with one another.
4. In a phase diagram, the slope of the curve between solid and gas may be negative.
5. The electrical conductivity of pure silicon crystal is lower than silicon with phosphorus impurity.
6. The boiling point of PH_3 is higher than that of SiH_4.
7. Temperature rising will lower the electrical conductivity of a silicon crystal.
8. A silicon crystal is an amorphous solid.
9. Silicon with phosphorus impurity is a N-type semiconductor.
10. The Maxwell-Boltzmann distribution for molecular speeds is an example of the normal distribution.
11. At the same temperature, $C_2H_4(g)$ and $N_2(g)$ have the same distribution of molecular speed.

12. The molecular speed distribution curve of a gas is not symmetric, and the mean square speed is not equal to the average speed.
13. The molecular speed distribution curve of a gas becomes broader when the temperature decreases.
14. The gas with a greater molecular mass has a broader molecular speed distribution curve than that with a smaller molecular mass
15. Neither matter nor heat may be transferred between system and surroundings in a closed system.

Part II. Multiple choice, Single answer, 2% each

16. Which of the following is false?
    (A) The heat change for a process at constant volume is equal to the change of internal energy.
    (B) The heat change for a process at constant pressure is equal to the change of enthalpy.
    (C) The work done by the system is a state function.
17. If 120 kJ of heat is required at constant pressure to decompose 0.5 mol of a substance to form its constituent elements in their standard states, then the standard enthalpy of formation of the substance is (A) 240 kJ. (B) 120 kJ. (C) -240 kJ. (D) -120 kJ.
18. A process that releases heat is
    (A) exothermic and its ΔH is positive.
    (B) endothermic and its ΔH is positive.
    (C) exothermic and its ΔH is negative.
    (D) endothermic and its ΔH is negative.
19. The enthalpy change for which of the following processes would correspond to the standard enthalpy of formation of sodium chloride?
    (A) $Na^+(aq) + Cl^-(aq) \rightarrow NaCl(s)$.
    (B) $2\ Na(s) + Cl_2(g) \rightarrow 2\ NaCl(s)$.
    (C) $Na(s) + Cl_2(g) \rightarrow NaCl(s)$.
    (D) $Na(s) + 1/2\ Cl_2(g) \rightarrow NaCl(s)$
20. Arrange these compounds in order of increasing standard molar entropy at 25℃:
    $C_3H_8(g)$, $C_2H_4(g)$, $ZnS(s)$, and $H_2O(l)$.
    (A) $ZnS(s) < H_2O(l) < C_3H_8(g) < C_2H_4(g)$
    (B) $ZnS(s) < H_2O(l) < C_2H_4(g) < C_3H_8(g)$
    (C) $C_2H_4(g) < H_2O(l) < C_3H_8(g) < NaCl(s)$
    (D) $ZnS(s) < C_3H_8(g) < C_2H_4(g) < H_2O(l)$
    (E) $C_3H_8(g) < C_2H_4(g) < H_2O(l) < ZnS(s)$
21. Which of the following processes are accompanied by an increase in entropy?
    1. $2\ SO_2(g) + O_2(g) \rightarrow SO_3(g)$
    2. $H_2O(l) \rightarrow H_2O(s)$
    3. $Br_2(l) \rightarrow Br_2(g)$
    4. $H_2O_2(l) \rightarrow H_2O(l) + 1/2\ O_2(g)$

(A) 1, 2, 3, 4 (B) 3, 4 (C) 1, 2 (D) 2, 3, 4 (E) 1, 4

22. Calculate $\Delta S°$ at 25℃ for the reduction of PbO(s), $2\ PbO(s) + C(s) \rightarrow 2\ Pb(s) + CO_2(g)$. Given that the absolute entropies of PbO(s), C(s), Pb(s), and $CO_2(g)$ are 69.45, 5.7, 64.89, and 213.6 $J \cdot mol^{-1} \cdot K^{-1}$, respectively.
    (A) +488.0 $J \cdot mol^{-1} \cdot K^{-1}$ (B) +353.6 $J \cdot mol^{-1} \cdot K^{-1}$ (C) +198.8 $J \cdot mol^{-1} \cdot K^{-1}$
    (D) -203.3 $J \cdot mol^{-1} \cdot K^{-1}$ (E) +203.3 $J \cdot mol^{-1} \cdot K^{-1}$
23. A negative sign for ΔG indicates that, at constant T and P,
    (A) the reaction is exothermic.
    (B) the reaction is spontaneous.
    (C) the reaction is endothermic.
    (D) the reaction is fast.
    (E) ΔS must be > 0
24. Sodium carbonate can be made by heating sodium bicarbonate:
    $2\ NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$
    Given that $\Delta H° = 128.9\ kJ \cdot mol^{-1}$ and $\Delta G° = 33.1\ kJ \cdot mol^{-1}$ at 25℃. Above what minimum temperature will the reaction become spontaneous under standard state conditions? Assumed the $\Delta H°$ and $\Delta S°$ do not change with temperature.
    (A) 525 K (B) 401 K (C) 321 K (D) 3.9 K (E) 0.4 K
25. For the reaction $H_2(g) + S(s) \rightarrow H_2S(g)$, $\Delta H° = -20.2$ kJ and $\Delta S° = +43.1\ J \cdot K^{-1}$. Which of these statements is true?
    (A) $\Delta G°$ becomes less favorable as temperature increases.
    (B) The reaction is spontaneous only at high temperatures.
    (C) The reaction is only spontaneous at low temperatures.
    (D) The reaction is spontaneous at all temperatures.
    (E) The reaction is at equilibrium at 25℃ under standard conditions.
26. The normal freezing point of ammonia is -78℃. Predict the signs of ΔH, ΔS, and ΔG for ammonia when it freezes at -80℃ and 1 atm: $NH_3(l) \rightarrow NH_3(s)$
    (A) $\Delta H < 0$, $\Delta S < 0$, and $\Delta G = 0$
    (B) $\Delta H < 0$, $\Delta S > 0$, and $\Delta G < 0$
    (C) $\Delta H > 0$, $\Delta S < 0$, and $\Delta G > 0$
    (D) $\Delta H > 0$, $\Delta S > 0$, and $\Delta G = 0$
    (E) $\Delta H < 0$, $\Delta S < 0$, and $\Delta G < 0$
27. A spontaneous endothermic reaction always
    (A) causes the surroundings to get colder.
    (B) bursts into flame.
    (C) requires a spark to initiate it.
    (D) releases heat to the surroundings.
28. Which species will have the greatest absolute entropy at 25℃?

(A) Ne(g) (B) C_2H_2(g) (C) H_2O(l) (D) C_2H_5OH(l) (E) C_4H_{10}(g)

Part III.

29. The van der Waals equation is an approximate equation of state for a real gas. In this equation, the parameter "*a*" represents the role of intermolecular attraction and the parameter "*b*" represents the effect of molecular or repulsion forces.
    (a) Which of the followings is the van der Waals equation? (2%)
    (A) $(P + an)(V - nb) = nRT$ (B) $(P + an^2)(V - nb) = nRT$
    (C) $\left(P + a\frac{n}{V}\right)(V - nb) = nRT$ (D) $\left(P + a\frac{n^2}{V^2}\right)(V - nb) = nRT$
    (E) $\left(P + a\frac{n^2}{V^2}\right)(V - n^2b) = nRT$
    (b) List the types of intermolecular forces between benzene (C_6H_6) molecules in the gas phase. (3%)
    (c) Both of benzene and oxygen are nonpolar, but the van der Waals parameter "*a*" for benzene (19.1 bar·L^2·mol^{-2}) is much larger than that for oxygen (1.37 bar·L^2·mol^{-2}). Please give three reasons for this? (3%)
    (d) When we combine the virial equation of state,
    $$\frac{PV}{nRT} = 1 + \frac{B}{\bar{V}} + \frac{C}{\bar{V}^2} + \frac{D}{\bar{V}^3} + \cdots$$
    and the van der Waals equation, the second virial coefficient $B = (b - a/RT)$ can be found. Please estimate the Boyle temperature of Ar neglecting terms containing virial coefficient higher than *B*. For Ar, given that a = 1.35 bar·L^2·mol^{-2} and b = 0.0322 L·mol^{-1}. (3%)
    (e) At the critical point of a van der Waals gas, we have $V_c = 3nb$, $P_c = a/27b^2$, $RT = 8a/27b$. Please find the compression factor *Z* of a van der Waals gas at the critical point.

30. Metallic aluminum crystallizes in a face-centered cubic lattice. The metallic radius of Al is 143 pm.
    (a) What is the coordination number of an aluminum atom in the lattice? (2%)
    (b) How many aluminum atoms are there in within a unit cell? (2%)
    (c) What is the length of a unit cell? (3%)
    (d) What is the density of the aluminum crystal? (3%)
    (e) When X-rays of wavelength 85 pm are diffracted by a aluminum crystal, the angle of the first-order diffraction (n = 1) is measure to be 10.56°. What is the distance between layers of atoms responsible for the diffraction. (3%)

31. Given that 2.00 mol of Ar gas are sealed in a 48.9 L rigid container at 298 K.
    (a) What is the kinetic energy of 1 mol of Ar? (2%)

(b) What is the root mean square speed of the Ar gas? (2%)

(c) If the collision frequency of Ar atom with one wall of the container is *N*, please find the molecule-wall collision frequency when the temperature is raised to 350 K. (2%)

32. Calculate how much methanol CH_3OH (in unit of gram) has to be burned in order to heat 1 mol of liquid water from 0℃ to 200℃ vapor. Given that the molar heat of combustion for methanol = -728 $kJ \cdot mol^{-1}$; enthalpy of vaporization for water is 40.8 $kJ \cdot mol^{-1}$; specific heat of water and steam are 4.18 and 1.99 $J \cdot g^{-1} \cdot ℃^{-1}$. (6%)

33. The $\bar{C}_P$ for ammonia (NH_3) is 35.1 $J \cdot mol^{-1} \cdot K^{-1}$ at 298 K. What percentage of this is due to vibrational motion? (6%)

34. The standard enthalpy change for the reaction $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$ is -571.6 kJ at 20℃. Calculate the stand reaction enthalpy change, $\Delta H°_{rxn}$, at 100℃. The $\bar{C}_P$ of $H_2(g)$, $O_2(g)$ and $H_2O(l)$ are 28.6, 29.4 and 75.2 $J \cdot mol^{-1} \cdot K^{-1}$ and these values do not depend on the temperature. (6%)

35. The N_2O molecule has the structure N-N-O. In an ordered crystal of N_2O, the molecules are lined up in a regular fashion, with the orientation of each determined by its position in the crystal. In a random crystal (formed on rapid freezing), each molecule has two equally likely orientations.

(a) Derive an equation to represent the number of microstates available to a random crystal of N_A (Avogadro's number) of molecules. (3%)

(b) Derive an equation to represent the entropy change when 1.00 mol of a random crystal is converted to an ordered crystal. (3%)

36. Solid tin exists in two forms: white and gray. For the transformation

$$Sn(s, white) \rightarrow Sn(s, gray)$$

the enthalpy change is -2.1 kJ and the entropy change is -7.4 $J \cdot K^{-1}$. Assume that ΔH and ΔS do not change with temperature. Use this data to answer the following questions.

(a) Will white tin convert spontaneously to gray tin at 25℃? (4%)

(b) Will white tin convert spontaneously to gray tin at -30℃? (4%)

104A Chemistry (I) Final Exam

Answer

Part I. 每題 1%，共 15%

1.	T	2.	F	3.	T	4.	F	5.	T
6.	T	7.	F	8.	F	9.	T	10.	F
11.	T	12.	T	13.	F	14.	F	15.	F

Part II. 每題 2%，共 26%

16.	C	17.	C	18.	C	19.	D	20.	B
21.	B	22.	C	23.	B	24.	B	25.	D
26.	E	27.	A	28.	E				

Part III.

29. 共 14%

(a) D (2%)

(b) London force (dispersion force) (3%)

(c) Benzene has larger molecular size, more electrons, delocalized bonds, and greater polarizability. 底線部分每項 1 分，最多得 3 分 (3%)

(d) At the Boyle temperature, the second virial coefficient $B = (b - a/RT) = 0$

for Ar, $\left(0.0322 - \frac{1.35}{0.08314 \times T}\right) = 0 \implies T = 504\ (K)$ (3%)

(e) at the critical point,

$$Z = \frac{PV}{nRT} = \frac{P_c V_c}{nRT_c} = \left(3nb \cdot \frac{a}{27b^2}\right) \Big/ \left(n \cdot \frac{8a}{27b}\right) = \frac{3}{8}$$

(3%)

30. 共 13%

(a) 12 (2%)

(b) 4 atoms (2%)

(c) $143 \times 4 \div 2^{1/2} = 404$ (pm) (3%)

(d) $4 \times (26.98/6\times10^{23})/(404\times10^{-10})^3 = 2.73$ (g/cm^3) (3%)

(e) Bragg's equation: $2d\sin\theta = n\lambda$, (2%)

$\theta = 10.56°$, $n = 1$, $\lambda = 85$ pm → $d = 232$ pm (1%，本小題共 3%)

31. 共 6%

(a) kinetic energy of 1 mol of Ar at 298 K = $3/2\times R\times T = 3.72\times10^3$ J (2%)

(b) $v_{rms} = (2\times3.72\times10^3/39.95\times10^{-3})^{1/2} = 4.32\times10^{-10}$ (m/s) (2%)

(c) the volume of the gas is constant → molecule-wall collision frequency is proportional to the v_{rms} → the collision frequency at 350 K = $(350/298)^{1/2} = 1.08$N (2%)

32. Energy required = 18×100×4.18 + 40.8×1000 + 18×100×1.99 = 51906 (J)
Heat of combustion of methanol per gram = 728000/32 = 22750 (J g^{-1})
51906 / 22750 = 2.28 g **(6%)**

33. Consider translational and rotational degrees of freedom,
$C_P = C_V + R = (3/2 + 3/2) \times R + R = 4R = 33.3$ J·mol^{-1}·K^{-1}
The vibrational contribution is 35.1 – 33.3 = 1.8 J·mol^{-1}·K^{-1}
The percentage pf contribution from vibrational motion = 1.8/35.1 = 5.1 % **(6%)**

34. $\Delta C_{P,rxn} = 2 \times 75.2 - (2 \times 28.6 + 29.4) = 150.4 - 86.6 = 63.8$ (J·mol^{-1}·K^{-1})
Using Kirchhoff's law, $\Delta H°_{rxn}(T_2) = \Delta H°_{rxn}(T_1) + \Delta C°_{P,rxn} \times \Delta T = -571.6 + (63.8/1000) \times 80 =$ -566 (kJ) **(6%)**

35. 共 **6%**
(a) number of microstates = $2^{6\times10^{23}}$ **(3%)**
(b) $\Delta S = k_B \, ln \, W_{ordered} - k_B \, ln \, W_{random} = k_B \ln \frac{1}{2^{6\times10^{23}}} = k_B \cdot (-6 \times 10^{23}) \ln 2$ **(不用計算，列出算式即可，3%)**

36. 共 **8%**
(a) T = 25℃ = 298 K , $\Delta G = -2.1\times10^3 - 298\times(-7.4) = 105$ (J) **(2%)**
$\Delta G > 0$, white tin will NOT convert spontaneously to gray tin at 25℃ **(2%)**
(b) T = -30℃ = 243 K , $\Delta G = -2.1\times10^3 - 243\times(-7.4) = -302$ (J) **(2%)**
$\Delta G < 0$, white tin will convert spontaneously to gray tin at -30℃ **(2%)**