

Name _____

The Gas Constant is: $R = 8.31 \text{ J/mol-K} = 8.31 \times 10^{-3} \text{ kJ/mol-K}$

(63) **PART I. MULTIPLE CHOICE (Circle the ONE correct answer)**

For #1 - #2: Consider the sparingly soluble compound, Lanthanum Iodate, $[\text{La}(\text{IO}_3)_3]$. The solubility product constant is $K_{\text{sp}} = 7.5 \times 10^{-12}$.

- What is the solubility of $\text{La}(\text{IO}_3)_3$ in pure water?

(A) $1.7 \times 10^{-3} \text{ M}$ (B) 7.3×10^{-4} (C) $6.5 \times 10^{-5} \text{ M}$ (D) $1.2 \times 10^{-4} \text{ M}$
- What is the **concentration of iodate ions**, $[\text{IO}_3^-]$, in a solution containing 2.0 M $\text{La}(\text{NO}_3)_3$ (which is a strong electrolyte)?

(A) $4.7 \times 10^{-4} \text{ M}$ (B) $5.2 \times 10^{-5} \text{ M}$ (C) $1.6 \times 10^{-4} \text{ M}$ (D) $6.5 \times 10^{-7} \text{ M}$
- The solubility products of two sparingly soluble Lead(II) $[\text{Pb}^{2+}]$ salts are: $\text{Pb}(\text{ClO}_3)_2 - K_{\text{sp}} = 5.6 \times 10^{-13}$, $\text{PbSO}_4 - K_{\text{sp}} = 1.6 \times 10^{-8}$.
Consider a solution which initially contains $1.0 \times 10^{-5} \text{ M ClO}_3^-(\text{aq})$ and $1.0 \times 10^{-5} \text{ M SO}_4^{2-}(\text{aq})$. $\text{Pb}(\text{NO}_3)_2$ (a strong electrolyte) is added until $[\text{Pb}^{2+}] = 7.0 \times 10^{-3} \text{ M}$.
Which of the above salts will form any solid precipitate?

(A) $\text{Pb}(\text{ClO}_3)_2$ only (B) PbSO_4 only (C) Neither $\text{Pb}(\text{ClO}_3)_2$ nor PbSO_4
(D) Both $\text{Pb}(\text{ClO}_3)_2$ and PbSO_4

- Which of the following statements is/are **NOT** correct?

(1) The entropy change on crystallizing liquid is positive
(2) The entropy usually increases when a liquid is dissolved in a second liquid
(3) The entropy of $\text{CaO}(\text{s})$ is higher than the entropy of $\text{CaCO}_3(\text{s})$
(4) The entropy increases when a gas dissolves in a liquid

(A) 1 & 4 (B) 1 & 3 & 4 (C) 1 & 3 (D) 2 only
- Consider the reaction: $\text{N}_2(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow 2 \text{NO}_2(\text{g})$, $\Delta H^\circ > 0$. This reaction is:

(A) Reactant Favored at all temperatures
(B) Product Favored at all temperatures
(C) Product Favored at low temperature
(D) Product Favored at high temperature

Version A

6. For the hypothetical reaction, $A \rightleftharpoons B$, $\Delta S^\circ = -70 \text{ J/K}$ (independent of temperature). The equilibrium constant for the reaction at 150°C is 2.0×10^{-3} . What is the enthalpy change, ΔH° for this reaction?
- (A) +51.5 kJ (B) -37.3 kJ (C) -7.8 kJ (D) -51.5 kJ
7. For the reaction, $\text{CH}_3\text{OH}(g) \rightleftharpoons \text{CO}(g) + 2\text{H}_2(g)$, $\Delta H^\circ = +91 \text{ kJ}$ and $\Delta S^\circ = +221 \text{ J/K}$. What is the entropy change of the **surroundings**, ΔS_{surr} , for the related reaction, $\frac{1}{2}\text{CH}_3\text{OH}(g) \rightleftharpoons \frac{1}{2}\text{CO}(g) + \text{H}_2(g)$, at 25°C ?
- (A) +111 J/K (B) +153 J/K (C) -111 J/K (D) -153 J/K
8. The normal boiling point of methane [CH_4 , $M=16$] is -162°C . The Enthalpy of Vaporization of methane is 8.5 kJ/mol . What is the entropy change of the **system** when 40 g of methane gas condenses to the liquid at -162°C ?
- (A) -191 J/K (B) $+191 \text{ J/K}$ (C) -131 J/K
(D) Requires the value of the Entropy of Vaporization

For #9 - #10: Consider the reaction: $2 \text{Fe}_2\text{O}_3(\text{s}) \rightarrow 4 \text{Fe}(\text{s}) + 3 \text{O}_2(\text{g})$

	Fe₂O₃(s)	Fe(s)	O₂(g)
S_m^o(25 °C)	87 J/mol-K	27 J/mol-K	205 J/mol-K
ΔG_f^o(25 °C)	-742 kJ/mol		

9. What is ΔG° for the above reaction [at 25°C] ?
- (A) -1484 kJ (B) $+742 \text{ kJ}$ (C) $+1484 \text{ kJ}$
(D) Insufficient Information is Given
10. What is the Enthalpy Change, ΔH° , for the above reaction [at 25°C]
- (A) $+1648 \text{ kJ}$ (B) -1320 kJ (C) $+1320 \text{ kJ}$
(D) Insufficient Information is Given
11. The reaction, $A \rightarrow B$, is **endergonic** at 25°C and the entropy change is $+40 \text{ J/K}$. What can be concluded about the enthalpy change for this reaction?
- (A) $\Delta H < -11.9 \text{ kJ}$ (B) $\Delta H > +11.9 \text{ kJ}$ (C) $\Delta H > 18.4 \text{ kJ}$
(D) No conclusion can be made about ΔH
12. For the **exergonic** reaction, $C \rightarrow D$, $\Delta H = +25 \text{ kJ}$. For this reaction,
- (A) $\Delta G < 0$ & $\Delta S < 0$ (B) $\Delta G > 0$ & $\Delta S < 0$ (C) $\Delta G > 0$ & $\Delta S > 0$ (D) $\Delta G < 0$ & $\Delta S > 0$

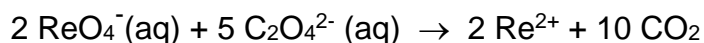
Version A

For #13 - #14: The Enthalpy of Vaporization of Br₂(liq) is 29.5 kJ/mol. The Entropy of Vaporization of Br₂(liq) is 89.0 J/mol-K.

13. The Entropy change of the universe, ΔS_{univ} , when one mole of Br₂(gas) condenses to Br₂(liq) at 90 °C is approximately:
- (A) +7.7 J/mol-K (B) -7.7 J/mol-K (C) +14.3 J/mol-K
(D) None of the above
14. The normal boiling point of Br₂(liq) is approximately:
- (A) 58 °C (B) 83 °C (C) 331 °C
(D) Depends upon the magnitude of ΔS_{univ}
15. Consider the gas phase reaction, $2 \text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2 \text{NOCl}(\text{g})$. The Gibbs Free Energy of Formation of NOCl(g) is $\Delta G_f^\circ(\text{NOCl}) = +66.1 \text{ kJ/mol}$. The value of the equilibrium constant, K, at 25 °C is approximately:
- (A) 2.6×10^{-12} (B) 6.5×10^{-24} (C) 1.5×10^{23}
(D) Insufficient data is given to determine the equilibrium constant
16. The equilibrium constant for the reaction, $2 \text{N}_2\text{O}_5 \rightleftharpoons 2 \text{N}_2(\text{g}) + 5 \text{O}_2(\text{g})$, is 2.4×10^{41} at 25 °C. What is the approximate value of the Gibbs Free Energy of Formation of N₂O₅(g)?
- (A) -118. kJ/mol (B) -236. kJ/mol (C) +118 kJ/mol
(D) Insufficient data is given to determine $\Delta G_f^\circ(\text{N}_2\text{O}_5)$
17. For the reaction, $2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{SO}_3(\text{g})$, the equilibrium constant is $K = 150$. at 300 °C. What is the approximate value of ΔG for this reaction at 300 °C when $P(\text{SO}_2) = 0.10 \text{ bar}$, $P(\text{O}_2) = 0.50 \text{ bar}$, and $P(\text{SO}_3) = 2.5 \text{ bar}$?
- (A) +10.1 kJ (B) -23.9 kJ (C) +34.0 kJ (D) -57.8 kJ
18. For the reaction, $2 \text{HI}(\text{g}) \rightleftharpoons \text{H}_2(\text{g}) + \text{I}_2(\text{g})$, $\Delta H^\circ = -53 \text{ kJ}$ and $\Delta S^\circ = -166 \text{ J/K}$. This reaction is _____ favored at temperatures **above** _____ °C (Celsius).
- (A) Product , 319 °C (B) Product , 46 °C
(C) Reactant , 319 °C (D) Reactant , 46 °C
19. As discussed in class, hydrophobic (non-polar) amino acid sidechains tend to reside in the interior of proteins' tertiary structure. The reason they do **not** reside on the exterior of the protein is that they would
- (A) lower the entropy of the surrounding water molecules
(B) raise the entropy of the surrounding water molecules
(C) raise the enthalpy of the non-polar sidechain
(D) hydrogen bond with the surrounding water molecules

Version A

20. In class, we discussed the thermodynamics of the formation of doubly stranded DNA by base-pairing of nucleic acids in the individual strands. Let's consider the **breaking** of one base-pair (e.g. Adenine-Thymine) in the unravelling of doubly stranded DNA. For this process, ΔH° is _____ and ΔS° is _____
- (A) Negative, Negative (B) Positive, Positive
(C) Positive, Negative (D) Negative, Positive
21. Regarding the following reaction, which of the statements below is/are **Not correct**?

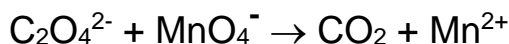


- (1) Re^{2+} is reduced (2) $\text{C}_2\text{O}_4^{2-}$ is Oxidized
(3) $\text{C}_2\text{O}_4^{2-}$ is the reducing agent (4) Five (5) electrons are transferred
- (A) 1 & 4 (B) 2 & 3 (C) 2 & 4 (D) 4 only
-

PART II. FOUR (4) PROBLEMS : REMEMBER TO SHOW WORK FOR CREDIT

The Gas Constant is: $R = 8.31 \text{ J/mol-K} = 8.31 \times 10^{-3} \text{ kJ/mol-K}$

- (5) 1. Write a balanced half reaction in **aqueous Acid** solution for the reaction of I_2 to form the IO_3^- ion.
- (10) 2. Balance the following oxidation-reduction reaction in **aqueous Basic** solution.



- (08) 3. Barium Phosphate, $\text{Ba}_3(\text{PO}_4)_2(\text{s})$, is a sparingly soluble salt with $K_{\text{sp}} = 3.0 \times 10^{-23}$. 6.0 L of $1.50 \times 10^{-4} \text{ M Ba}(\text{NO}_3)_2(\text{aq})$ is mixed with 4.0 L of $1.00 \times 10^{-5} \text{ M Na}_3\text{PO}_4(\text{aq})$. Use this data to **calculate whether or not** any $\text{Ba}_3(\text{PO}_4)_2(\text{s})$ will precipitate when the two solutions are mixed. You **MUST** show your calculation to receive credit.

- (14) 4. Consider the gas phase equilibrium, $2 \text{PBr}_3(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{POBr}_3(\text{g})$. The equilibrium constant for this reaction is $K = 0.04$ at 200°C .
- (10) (a) If the pressures of $\text{O}_2(\text{g})$ and $\text{POBr}_3(\text{g})$ are both 0.55 bar, what is the pressure of $\text{PBr}_3(\text{g})$ if the Gibbs Free Energy change is $\Delta G = 7.00 \text{ kJ}$ at 200°C ?
- (4) (b) What is the value of K for the related reaction, $\text{POBr}_3(\text{g}) \rightleftharpoons \text{PBr}_3(\text{g}) + \frac{1}{2} \text{O}_2(\text{g})$?

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(63) **PART I. MULTIPLE CHOICE (Circle the ONE correct answer)**

1. The solubility products of two sparingly soluble Lead(II) $[\text{Pb}^{2+}]$ salts are:
 $\text{Pb}(\text{ClO}_3)_2 - K_{\text{sp}} = 5.6 \times 10^{-13}$, $\text{PbSO}_4 - K_{\text{sp}} = 1.6 \times 10^{-8}$.

Consider a solution which initially contains $1.0 \times 10^{-5} \text{ M ClO}_3^- (\text{aq})$ and $1.0 \times 10^{-5} \text{ M SO}_4^{2-} (\text{aq})$. $\text{Pb}(\text{NO}_3)_2$ (a strong electrolyte) is added until $[\text{Pb}^{2+}] = 7.0 \times 10^{-3} \text{ M}$.

Which of the above salts will form any solid precipitate?

- (A) $\text{Pb}(\text{ClO}_3)_2$ only (B) PbSO_4 only (C) Both $\text{Pb}(\text{ClO}_3)_2$ and PbSO_4
 (D) Neither $\text{Pb}(\text{ClO}_3)_2$ nor PbSO_4

For #2 - #3: Consider the sparingly soluble compound, Lanthanum Iodate, $[\text{La}(\text{IO}_3)_3]$.
 The solubility product constant is $K_{\text{sp}} = 7.5 \times 10^{-12}$.

2. What is the solubility of $\text{La}(\text{IO}_3)_3$ in pure water?

- (A) $7.3 \times 10^{-4} \text{ M}$ (B) 1.7×10^{-3} (C) $6.5 \times 10^{-5} \text{ M}$ (D) $1.2 \times 10^{-4} \text{ M}$

3. What is the **concentration of iodate ions**, $[\text{IO}_3^-]$, in a solution containing 2.0 M $\text{La}(\text{NO}_3)_3$ (which is a strong electrolyte)?

- (A) $4.7 \times 10^{-4} \text{ M}$ (B) $5.2 \times 10^{-5} \text{ M}$ (C) $6.5 \times 10^{-7} \text{ M}$ (D) $1.6 \times 10^{-4} \text{ M}$

4. Consider the reaction: $\text{N}_2(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow 2 \text{NO}_2(\text{g})$, $\Delta H^\circ > 0$. This reaction is:

- (A) Product Favored at all temperatures
 (B) Reactant Favored at all temperatures
 (C) Product Favored at low temperature
 (D) Product Favored at high temperature

5. Which of the following statements is/are **NOT** correct?

- (1) The entropy change on crystallizing liquid is positive
 (2) The entropy usually increases when a liquid is dissolved in a second liquid
 (3) The entropy of $\text{CaO}(\text{s})$ is higher than the entropy of $\text{CaCO}_3(\text{s})$
 (4) The entropy increases when a gas dissolves in a liquid

- (A) 1 & 4 (B) 1 & 3 (C) 1 & 3 & 4 (D) 2 only

Version B

6. The normal boiling point of methane [CH₄, M=16] is -162 °C. The Enthalpy of Vaporization of methane is 8.5 kJ/mol. What is the entropy change of the **system** when 40 g of methane gas condenses to the liquid at -162 °C?
- (A) +191 J/K (B) -191 J/K (C) -131 J/K
(D) Requires the value of the Entropy of Vaporization
7. For the reaction, $CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$, $\Delta H^\circ = +91$ kJ and $\Delta S^\circ = +221$ J/K. What is the entropy change of the **surroundings**, ΔS_{surr} , for the related reaction, $\frac{1}{2}CH_3OH(g) \rightleftharpoons \frac{1}{2}CO(g) + 1H_2(g)$, at 25 °C?
- (A) +111 J/K (B) +153 J/K (C) -153 J/K (D) -111 J/K

For #8 - #9: Consider the reaction: $2 Fe_2O_3(s) \rightarrow 4 Fe(s) + 3 O_2(g)$

	Fe₂O₃(s)	Fe(s)	O₂(g)
S_m^o(25 °C)	87 J/mol-K	27 J/mol-K	205 J/mol-K
ΔG_r^o(25 °C)	-742 kJ/mol		

8. What is ΔG° for the above reaction [at 25 °C] ?
- (A) +1484 kJ (B) +742 kJ (C) -1484 kJ
(D) Insufficient Information is Given
9. What is the Enthalpy Change, ΔH° , for the above reaction [at 25 °C]
- (A) -1320 kJ (B) +1648 kJ (C) +1320 kJ
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10. For the hypothetical reaction, $A \rightleftharpoons B$, $\Delta S^\circ = -70$ J/K (independent of temperature). The equilibrium constant for the reaction at 150 °C is 2.0×10^{-3} . What is the enthalpy change, ΔH° for this reaction?
- (A) +51.5 kJ (B) -37.3 kJ (C) -51.5 kJ (D) -7.8 kJ
11. For the **exergonic** reaction, $C \rightarrow D$, $\Delta H = +25$ kJ. For this reaction,
- (A) $\Delta G < 0$ & $\Delta S < 0$ (B) $\Delta G > 0$ & $\Delta S < 0$ (C) $\Delta G < 0$ & $\Delta S > 0$ (D) $\Delta G > 0$ & $\Delta S > 0$
12. The reaction, $A \rightarrow B$, is **endergonic** at 25 °C and the entropy change is +40 J/K. What can be concluded about the enthalpy change for this reaction?
- (A) $\Delta H > +11.9$ kJ (B) $\Delta H < -11.9$ kJ (C) $\Delta H > 18.4$ kJ
(D) No conclusion can be made about ΔH

Version B

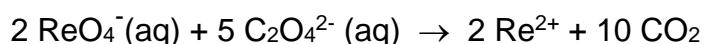
13. The equilibrium constant for the reaction, $2 \text{N}_2\text{O}_5 \rightleftharpoons 2 \text{N}_2(\text{g}) + 5 \text{O}_2(\text{g})$, is 2.4×10^{41} at 25°C . What is the approximate value of the Gibbs Free Energy of Formation of $\text{N}_2\text{O}_5(\text{g})$?
- (A) +118. kJ/mol (B) -236. kJ/mol (C) -118 kJ/mol
(D) Insufficient data is given to determine $\Delta G_f^\circ(\text{N}_2\text{O}_5)$
14. Consider the gas phase reaction, $2 \text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2 \text{NOCl}(\text{g})$. The Gibbs Free Energy of Formation of $\text{NOCl}(\text{g})$ is $\Delta G_f^\circ(\text{NOCl}) = +66.1 \text{ kJ/mol}$. The value of the equilibrium constant, K , at 25°C is approximately:
- (A) 2.6×10^{-12} (B) 6.5×10^{-24} (C) 1.5×10^{23}
(D) Insufficient data is given to determine the equilibrium constant

For #15 - #16: The Enthalpy of Vaporization of $\text{Br}_2(\text{liq})$ is 29.5 kJ/mol . The Entropy of Vaporization of $\text{Br}_2(\text{liq})$ is 89.0 J/mol-K .

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- (A) $+7.7 \text{ J/mol-K}$ (B) -7.7 J/mol-K (C) $+14.3 \text{ J/mol-K}$
(D) None of the above
16. The normal boiling point of $\text{Br}_2(\text{liq})$ is approximately:
- (A) 331°C (B) 83°C (C) 58°C
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17. For the reaction, $2 \text{HI}(\text{g}) \rightleftharpoons \text{H}_2(\text{g}) + \text{I}_2(\text{g})$, $\Delta H^\circ = -53 \text{ kJ}$ and $\Delta S^\circ = -166 \text{ J/K}$. This reaction is _____ favored at temperatures **above** _____ $^\circ\text{C}$ (Celsius).
- (A) Reactant , 46°C (B) Product , 46°C
(C) Reactant , 319°C (D) Product , 319°C
18. For the reaction, $2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{SO}_3(\text{g})$, the equilibrium constant is $K = 150$. at 300°C . What is the approximate value of ΔG for this reaction at 300°C when $P(\text{SO}_2) = 0.10 \text{ bar}$, $P(\text{O}_2) = 0.50 \text{ bar}$, and $P(\text{SO}_3) = 2.5 \text{ bar}$?
- (A) -57.8 kJ (B) $+10.1 \text{ kJ}$ (C) $+34.0 \text{ kJ}$ (D) -23.9 kJ
19. In class, we discussed the thermodynamics of the formation of doubly stranded DNA by base-pairing of nucleic acids in the individual strands. Let's consider the **breaking** of one base-pair (e.g. Adenine-Thymine) in the unravelling of doubly stranded DNA. For this process, ΔH° is _____ and ΔS° is _____
- (A) Negative, Negative (B) Negative, Positive
(C) Positive, Negative (D) Positive, Positive

Version B

20. As discussed in class, hydrophobic (non-polar) amino acid sidechains tend to reside in the interior of proteins' tertiary structure. The reason they do **not** reside on the exterior of the protein is that they would
- (A) raise the entropy of the surrounding water molecules
 - (B) lower the entropy of the surrounding water molecules
 - (C) raise the enthalpy of the non-polar sidechain
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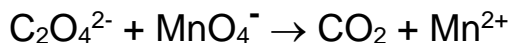


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|---|---|-----------|-----------|
| (1) Re^{2+} is reduced | (2) $\text{C}_2\text{O}_4^{2-}$ is Oxidized | | |
| (3) $\text{C}_2\text{O}_4^{2-}$ is the reducing agent | (4) Five (5) electrons are transferred | | |
| (A) 4 only | (B) 2 & 3 | (C) 2 & 4 | (D) 1 & 4 |

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- (10) (a) If the pressures of $\text{O}_2(\text{g})$ and $\text{POBr}_3(\text{g})$ are both 0.65 bar, what is the pressure of $\text{PBr}_3(\text{g})$ if the Gibbs Free Energy change is $\Delta G = 7.00 \text{ kJ}$ at 200°C ?
- (4) (b) What is the value of K for the related reaction, $\text{POBr}_3(\text{g}) \rightleftharpoons \text{PBr}_3(\text{g}) + \frac{1}{2} \text{O}_2(\text{g})$?