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Directions:

1. The exam has 61 multiple choice questions that are equally weighted at 5 points each.
2. A calculator and a four page crib sheet (8.5 x 11, front only) are permitted for use during the exam.
3. Complete the scantron card and include, your name, your TA, your lecture professor, your GT ID (bubble in the appropriate numbers), and the exam version. All of this material must be submitted to receive credit.
4. Cell phones must be shut off during the exam.
5. A maximum of 170 minutes is allowed for the exam.
6. When you are finished or when time is called, submit your exam to your TA, show your buzz card or other photo ID for identification.
7. You may not leave the exam room until 50 minutes have lapsed.
8. A periodic table is provided at the end of the exam.
9. Only the answers submitted on the scantron card will be graded.

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## Section 1 (questions 1-14)

1. Determine the molecular formula of a compound that has a molecular weight of 366 g/mol and an empirical formula of  $C_2H_5O_2$ .
- A)  $C_3H_7O_3$
  - B)  $C_6H_{15}O_6$
  - C)  $C_{12}H_{30}O_{12}$
  - D)  $C_2H_5O_2$
  - E)  $C_8H_{20}O_8$

Answer: C

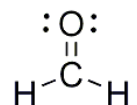
2. The ratio of the number of bismuth atoms to the number of oxygen atoms in  $Bi_2(SO_4)_3$  is
- A) 1:6
  - B) 2:7
  - C) 2:3
  - D) 2:1
  - E) none of these

Answer: A

3. Which species below is trigonal planar?
- A)  $NH_4^+$
  - B)  $SO_3^{2-}$
  - C)  $ClO_3^-$
  - D)  $NH_3$
  - E)  $CO_3^{2-}$

Answer: E

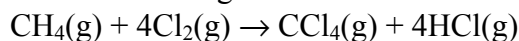
4. The bond angles about the carbon atom in the formaldehyde molecule ( $H_2C=O$ , below) are:



- A)  $\approx 60^\circ$
- B)  $\approx 109^\circ$
- C)  $\approx 180^\circ$
- D)  $\approx 120^\circ$
- E)  $\approx 90^\circ$

Answer: D

5. Consider the following reaction:



What mass of  $\text{CCl}_4$  will be formed if 1.20 moles of methane ( $\text{CH}_4$ ) react with 1.60 moles of chlorine?

- A) 229 g
- B) 171 g
- C) 114 g
- D) 61.5 g
- E) 17.1 g

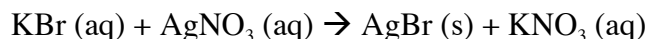
Answer: D

6. How many liters of a 0.0555 M KCl solution contain 0.163 moles of  $\text{Cl}^-$ ?

- A) 1.12 L
- B) 3.37 L
- C) 8.98 L
- D) 1.48 L
- E) 2.95 L

Answer: E

7. Identify the spectator ion(s) in the following molecular equation:



- A)  $\text{K}^+$  and  $\text{NO}_3^-$
- B)  $\text{K}^+$  and  $\text{Br}^-$
- C)  $\text{Ag}^+$  and  $\text{NO}_3^-$
- D)  $\text{Ag}^+$  and  $\text{Br}^-$
- E)  $\text{NO}_3^-$  only

Answer: A

8. Which solution has the greatest concentration of chloride ions ( $\text{Cl}^-$ )?

- A) 0.06 M  $\text{MgCl}_2$
- B) 0.05 M  $\text{CaCl}_2$
- C) 0.13 M  $\text{NaCl}$
- D) 0.04 M  $\text{CCl}_4$
- E) 0.05 M  $\text{AlCl}_3$

Answer: E,  $\text{CCl}_4$  is a covalent molecule that does not dissociate.

9. What is the oxidation state of "P" in  $\text{PO}_3^{3-}$ ?

- A) +3
- B) +6
- C) -3
- D) 0
- E) +2

Answer: A

10. Which of the following electronic transitions of a hydrogen atom would yield the longest wavelength of light as a result of atomic emission?
- A)  $n = 4$  to  $n = 2$
  - B)  $n = 3$  to  $n = 4$
  - C)  $n = 3$  to  $n = 1$
  - D)  $n = 1$  to  $n = 2$
  - E)  $n = 5$  to  $n = 4$

Answer: E

11. How many orbitals are contained in the third shell ( $n = 3$ ) of a given atom?
- A) 18
  - B) 9
  - C) 3
  - D) 5
  - E) 7

Answer: B

12. Oxygen has \_\_\_ valence electrons.
- A) 6
  - B) 4
  - C) 5
  - D) 7
  - E) 2

Answer: A

13. Place the following in order of ionic radius:

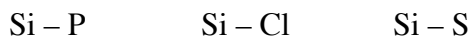


*Smallest to Largest*

- A)  $\text{Rb}^+ < \text{Br}^- < \text{Na}^+$
- B)  $\text{Br}^- < \text{Na}^+ < \text{Rb}^+$
- C)  $\text{Na}^+ < \text{Rb}^+ < \text{Br}^-$
- D)  $\text{Br}^- < \text{Rb}^+ < \text{Na}^+$
- E)  $\text{Rb}^+ < \text{Na}^+ < \text{Br}^-$

Answer: C

14. Place the following bonds in order of ionic character:



*Smallest to Greatest*

- A)  $\text{Si-P} < \text{Si-S} < \text{Si-Cl}$
- B)  $\text{Si-Cl} < \text{Si-S} < \text{Si-P}$
- C)  $\text{Si-Cl} < \text{Si-P} < \text{Si-S}$
- D)  $\text{Si-S} < \text{Si-Cl} < \text{Si-P}$
- E)  $\text{Si-P} < \text{Si-Cl} < \text{Si-S}$

Answer: A

**Section 2 (questions 15-28)**

15. What is the pH of a 0.2 M solution of  $\text{NH}_4\text{Cl}$  (aq)?  $K_b$  for  $\text{NH}_3$  is  $1.8 \times 10^{-5}$ .

- A) 2.7
- B) 5.0
- C) 7.0
- D) 9.0
- E) 11.3

Answer: B

$$K_w = K_b/K_a; K_a = 5.6 \times 10^{-10}$$

$$\text{pH} = -\log(\text{SQRT}(5.6 \times 10^{-10} \times 0.2)) = 5.0$$

16. To calculate the freezing point of an ideal dilute solution containing a single non-dissociating solute, the minimum information one must know is

- I the molality.
- II the molarity.
- III the freezing-point-depression constant of the solvent.
- IV the freezing point of the pure solvent.
- V the molecular weight of the solute.

- A) I, III
- B) II, III
- C) II, III, IV, V
- D) II, III, IV
- E) I, III, IV

\*Answer: E

17. For the reactions 1 and 2,  $K_1 = 10^2$  and  $K_2 = 10^{-4}$ .

1.  $\text{A}_2(\text{g}) + \text{B}_2(\text{g}) \rightleftharpoons 2\text{AB}(\text{g})$
2.  $2\text{A}_2(\text{g}) + \text{C}_2(\text{g}) \rightleftharpoons 2\text{A}_2\text{C}(\text{g})$
3.  $\text{A}_2\text{C}(\text{g}) + \text{B}_2(\text{g}) \rightleftharpoons 2\text{AB}(\text{g}) + (1/2)\text{C}_2(\text{g})$

What is  $K_3$  ?

- A)  $10^{-2}$
- B)  $10^4$
- C)  $10^6$
- D)  $10^2$
- E)  $10^{-4}$

Answer: B

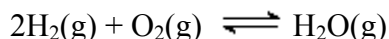
$$\text{Reaction 3} = \text{reaction 1} - 1/2(\text{reaction 2})$$

18. The boiling point of pure benzene at 760 torr is 80.1°C. What is the vapor pressure of benzene over an *ideal* solution containing 1.00 mole of a nonvolatile solute and 12.0 moles of benzene at 80.1°C?
- A) 63.0 torr  
 B) 695 torr  
 C) 702 torr  
 D) 760 torr  
 E) 823 torr

Answer: C

$$X P^\circ = (1.0/13)760 = 702$$

19. To increase the value of K for the following exothermic reaction



- A) increase the total pressure.  
 B) decrease the total pressure.  
 C) increase the temperature.  
 D) decrease the temperature.  
 E) add H<sub>2</sub>.

Answer: D, the reaction evolves heat. Remove heat from the system to drive it forward.

20. Which of the following exhibits the correct ranking of atomic radius and first ionization energy?

- A) Atomic Radius: S < O < F and Ionization Energy: F < O < S  
 B) Atomic Radius: S < O < F and Ionization Energy: O < S < F  
 C) Atomic Radius: S < F < O and Ionization Energy: S < F < O  
 D) Atomic Radius: F < O < S and Ionization Energy: S < O < F  
 E) Atomic Radius: F < O < S and Ionization Energy: O < S < F

Answer: D

21. Place the following three substances in order of increasing boiling point.

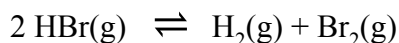
CH <sub>3</sub> CH <sub>2</sub> OCH <sub>2</sub> CH <sub>3</sub>	Ar	CH <sub>3</sub> OCH <sub>3</sub>
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smallest to largest

- A) Ar < CH<sub>3</sub>OCH<sub>3</sub> < CH<sub>3</sub>CH<sub>2</sub>OCH<sub>2</sub>CH<sub>3</sub>  
 B) CH<sub>3</sub>CH<sub>2</sub>OCH<sub>2</sub>CH<sub>3</sub> < Ar < CH<sub>3</sub>OCH<sub>3</sub>  
 C) Ar < CH<sub>3</sub>CH<sub>2</sub>OCH<sub>2</sub>CH<sub>3</sub> < CH<sub>3</sub>OCH<sub>3</sub>  
 D) CH<sub>3</sub>CH<sub>2</sub>OCH<sub>2</sub>CH<sub>3</sub> < CH<sub>3</sub>OCH<sub>3</sub> < Ar  
 E) CH<sub>3</sub>OCH<sub>3</sub> < Ar < CH<sub>3</sub>CH<sub>2</sub>OCH<sub>2</sub>CH<sub>3</sub>

Answer: A

22. Consider the following reaction at equilibrium. What effect will reducing the volume of the reaction mixture have on the system?



- A) No effect
- B) The reaction will shift to the left
- C) The reaction will shift to the right
- D) The equilibrium constant will increase
- E) The equilibrium constant will decrease

Answer: A

23. What is the pH of pure water at 40°C if the  $K_w$  at this temperature is  $2.92 \times 10^{-14}$ ?
- A) 0.47
  - B) 8.45
  - C) 6.77
  - D) 7.23
  - E) 7.00

Answer: C

24. What is the volume of 0.780 moles of He (g) at STP (273K, 1 atm) ?
- A) 43.7 L
  - B) 17.5 L
  - C) 70.0 L
  - D) 15.6 L
  - E) 22.4 L

Answer: B

25. Determine the pH of a 50 mL 0.116 M NaOH solution after dilution by the addition of 100 mL of water.
- A) 13.1
  - B) 13.4
  - C) 12.6
  - D) 11.4
  - E) 12.9

Answer: C

26. Determine the volume of  $\text{SO}_2$  (at STP= 273K, 1 atm) formed from the complete reaction of 96.7 grams of  $\text{FeS}_2$  (molecular weight = 120 g/mol) and 55.0 L of  $\text{O}_2$  (398 K, 1.20 atm).



- A) 27.6 L
- B) 36.1 L
- C) 18.1 L
- D) 32.9 L
- E) 45.3 L

Answer: D



$$\text{FeS}_2: (96.7 \text{ g})[4(120 \text{ g/mol})]^{-1} = 0.20 \text{ mol}$$

$$\text{O}_2: (55.0 \text{ L})(1.2 \text{ atm}) [11(0.082 \text{ L-atm/mole-K})(398 \text{ K})]^{-1} = 0.18 \text{ mol}$$

O<sub>2</sub> is the limiting reagent.

$$\text{Use } V = nRT/P = 8(0.18 \text{ mol})(0.082 \text{ L-atm/mole-K})(273 \text{ K})(1.0 \text{ atm})^{-1} = 32.3 \text{ L}$$

27. What is the conjugate acid of H<sub>2</sub>O ?

- A) H<sub>2</sub>O
- B) PO<sub>4</sub><sup>3-</sup>
- C) H<sub>3</sub>O<sup>+</sup>
- D) H<sub>2</sub>PO<sub>4</sub><sup>-</sup>
- E) OH<sup>-</sup>

Answer: C

28. Which of the following statements is TRUE?

- A) The equilibrium constant for the forward reaction is equal to the equilibrium constant for the reverse reaction.
- B) Equilibrium indicates that the amounts of reactants and products are equal.
- C) When the reaction quotient (Q) is larger than the equilibrium constant, the reaction will proceed in the forward direction.
- D) The forward and reverse reactions stop at equilibrium.
- E) The reaction shows no macroscopic evidence of change at equilibrium.

Answer: E



### Section 3 (questions 29-42)

Initially, a warm brick (the system) is placed in a cold pool of water (the surroundings). Finally, the system and surroundings reach thermal equilibrium. For this process:

29. A)  $\Delta S_{\text{system}} > 0$  and  $\Delta S_{\text{surroundings}} < 0$   
 B)  $\Delta S_{\text{system}} = 0$  and  $\Delta S_{\text{surroundings}} < 0$   
 C)  $\Delta S_{\text{system}} > 0$  and  $\Delta S_{\text{surroundings}} > 0$   
 D)  $\Delta S_{\text{system}} < 0$  and  $\Delta S_{\text{surroundings}} > 0$   
 E)  $\Delta S_{\text{system}} < 0$  and  $\Delta S_{\text{surroundings}} < 0$
30. A)  $\Delta S_{\text{universe}} > 0$  and  $\Delta E_{\text{universe}} = 0$   
 B)  $\Delta S_{\text{universe}} > 0$  and  $\Delta E_{\text{universe}} < 0$   
 C)  $\Delta S_{\text{universe}} < 0$  and  $\Delta E_{\text{universe}} = 0$   
 D)  $\Delta S_{\text{universe}} < 0$  and  $\Delta E_{\text{universe}} > 0$   
 E)  $\Delta S_{\text{universe}} = 0$  and  $\Delta E_{\text{universe}} = 0$

31. A 140 g sample of water at 25.0°C is mixed with 100 g of a solid metal at 100°C. After thermal equilibrium is established, the (final) temperature of the water and metal are both 29.6°C. What is the heat capacity of the metal, assuming it is constant? The specific heat capacity,  $c_s$ , for water is 4.184 J/g °C.
- A) 0.38 J/g °C  
 B) 0.76 J/g °C  
 C) 0.96 J/g °C  
 D) 0.031 J/g °C  
 E) 0.64 J/g °C

Answer: A

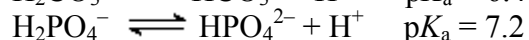
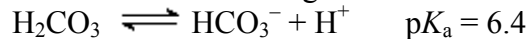
32. A 100 mL solution contains 1.0 M HNO<sub>2</sub> and 0.70 M NaNO<sub>2</sub>. 10 mL of 1.5 M HCl is added. The  $K_a$  for HNO<sub>2</sub> is  $7.2 \times 10^{-4}$ . Calculate the final pH.
- A) 1.9  
 B) 3.5  
 C) 2.8  
 D) 3.1  
 E) 0.2

Answer C

	NaNO <sub>2</sub>	+ HCl	→	HNO <sub>2</sub>	
I	0.070			0.015	0.100
C	-0.015			-0.015	+0.015
E	0.055			+0.000	0.115

$$\text{pH} = \text{p}K_a + \log(\text{Base}/\text{Acid}) = 3.14 + \log(0.055/0.115) = 2.8$$

33. Consider a solution consisting of two acids in water:

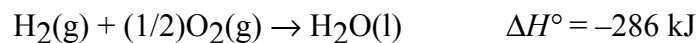


At pH 6.4, which one of the following is true?

- A)  $[\text{H}_2\text{CO}_3] > [\text{HCO}_3^-]$  and  $[\text{H}_2\text{PO}_4^-] > [\text{HPO}_4^{2-}]$   
 B)  $[\text{H}_2\text{CO}_3] = [\text{HCO}_3^-]$  and  $[\text{H}_2\text{PO}_4^-] > [\text{HPO}_4^{2-}]$   
 C)  $[\text{H}_2\text{CO}_3] = [\text{HCO}_3^-]$  and  $[\text{H}_2\text{PO}_4^-] < [\text{HPO}_4^{2-}]$   
 D)  $[\text{H}_2\text{CO}_3] > [\text{HCO}_3^-]$  and  $[\text{H}_2\text{PO}_4^-] = [\text{HPO}_4^{2-}]$   
 E)  $[\text{H}_2\text{CO}_3] < [\text{HCO}_3^-]$  and  $[\text{H}_2\text{PO}_4^-] = [\text{HPO}_4^{2-}]$

Answer: B

34. If  $2.0 \times 10^8$  L of hydrogen ( $\text{H}_2$ ) at 1.0 atm and  $0^\circ\text{C}$  is combined with excess oxygen and ignited, how much energy will be evolved?



- A)  $3.5 \times 10^{11}$  kJ  
 B)  $8.2 \times 10^6$  kJ  
 C)  $2.9 \times 10^4$  kJ  
 D)  $2.6 \times 10^9$  kJ  
 E)  $5.7 \times 10^{10}$  kJ

Answer: D

$$(-286) 2 \times 10^8 / 22.4 = 25.5 \times 10^8 \text{ kJ}$$

35. 100 ml of 0.1 M HCl and 100 ml of 0.1 M  $\text{CH}_3\text{COOH}$  are each titrated with 0.1 M NaOH. Which of the following would be equal for the two titrations?

- A) the initial pH  
 B) the initial  $[\text{H}^+]$   
 C) the buffering capacity at the  $\text{p}K_a$  of  $\text{CH}_3\text{COOH}$   
 D) the volume of NaOH added to reach equivalence point  
 E) none of the above

Answer: D

[use this information to answer the next two questions] 1.22 moles of perfect monatomic gas is very slowly expanded from 20 L to 30 L at a constant pressure of 5.0 atm ( $R = 0.082$  L-atm/mol-K;  $R = 8.31$  J/mol-K;  $101$  J/L-atm).

36. The heat  $q$  for this process is

- A) 9.8 kJ  
 B) -9.8 kJ  
 C) 271 kJ  
 D) 12.7 kJ  
 E) -12.7 kJ

Answer: D

$$T_i = PV/nR = (5.0 \text{ atm})(30 \text{ L}) / (0.082 \text{ L-atm/mol-K})(1.22 \text{ mol}) = 1500 \text{ K}$$

$$T_f = PV/nR = (5.0 \text{ atm})(15 \text{ L}) / (0.082 \text{ L-atm/mol-K})(0.171 \text{ mol}) = 1000 \text{ K}$$

$$q = nC_p\Delta T = n(5R/2)\Delta T = (1.22 \text{ mol})(5/2)(0.082 \text{ L-atm/mol-K})(1000\text{K}-1500\text{K}) = -125 \text{ L-atm}$$

$$(-125 \text{ L-atm})(101 \text{ J/L-atm}) = 12700 \text{ J} = 12.7 \text{ kJ}$$

37. The work  $w$  for this process is

- A) -5.05 kJ
- B) +5.05 kJ
- C) 13.5 kJ
- D) -13.5 kJ
- E) 27.1 kJ

Answer: A

$$w = -P\Delta V = -5(30-20) = -50 \text{ L atm}$$

$$(+50 \text{ L-atm})(101 \text{ J/L-atm}) = -5.05 \text{ kJ}$$

38. In a solution prepared by adding excess  $\text{MgF}_2(\text{s})$  [ $K_{\text{sp}} = 1.08 \times 10^{-10}$ ] to water,  $[\text{Mg}^{2+}]$  at equilibrium is:

- A)  $1.5 \times 10^{-4} \text{ mol/L}$
- B)  $2.4 \times 10^{-4} \text{ mol/L}$
- C)  $1.2 \times 10^{-4} \text{ mol/L}$
- D)  $3.0 \times 10^{-4} \text{ mol/L}$
- E)  $8.4 \times 10^{-6} \text{ mol/L}$

Answer D



$$K_{\text{sp}} = [\text{Mg}^{2+}][\text{F}^-]^2 = [\text{Mg}^{2+}](2[\text{Mg}^{2+}])^2 = 4([\text{Mg}^{2+}])^3 = 1.08 \times 10^{-10}$$

39. Using the following data, calculate the standard heat of formation of two moles of the compound  $\text{ICl}(\text{g})$  from  $\text{I}_2(\text{g})$  and  $\text{Cl}_2(\text{g})$ :

	$\Delta H^\circ$ (kJ/mol)
$\text{Cl}_2(\text{g}) \rightarrow 2\text{Cl}(\text{g})$	242
$\text{I}_2(\text{g}) \rightarrow 2\text{I}(\text{g})$	150
$\text{ICl}(\text{g}) \rightarrow \text{I}(\text{g}) + \text{Cl}(\text{g})$	211
$\text{I}_2(\text{s}) \rightarrow \text{I}_2(\text{g})$	63

- A) -211 kJ/mol
- B) -15 kJ/mol
- C) -30 kJ/mol
- D) +30 kJ/mol
- E) 181 kJ/mol

Answer: C



40. For the reaction  $A + B \rightarrow C + D$ ,  
 $\Delta H^\circ = 40 \text{ kJ/mol}$  and  $\Delta S^\circ = 50 \text{ J/mol-K}$ .  
The reaction under standard conditions is
- A) spontaneous reverse at temperatures greater than 800 K.
  - B) spontaneous forward at temperatures greater than 800 K.
  - C) spontaneous reverse only at temperatures greater than 600 K.
  - D) spontaneous forward at all temperatures.
  - E) spontaneous reverse at all temperatures.

Answer B

$\Delta H < 0 \Rightarrow$  spontaneous reverse at low T.

$\Delta S < 0 \Rightarrow$  spontaneous forward at high T.

Crossover Temperature =  $\Delta H/\Delta S = 40/0.050 = 800 \text{ K}$ . Spontaneous reverse at  $T > 800 \text{ K}$

41. Consider the freezing of liquid water at  $-10^\circ\text{C}$  and 1 atm. For this process what are the signs for  $\Delta H$ ,  $\Delta S$ , and  $\Delta G$ ?

	$\Delta H$	$\Delta S$	$\Delta G$
A)	+	-	0
B)	-	+	0
C)	-	+	-
D)	+	-	-
E)	-	-	-

Answer: E

The process is spontaneous;  $\Delta G < 0$ , exothermic;  $\Delta H < 0$ , and is changes directions at high temperature;  $\Delta S < 0$

42.  $\Delta G = \Delta G^\circ + RT \ln(Q)$

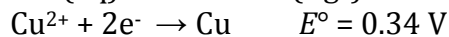
When  $\Delta G = 0$ ,

- A)  $Q > K$
- B)  $Q < K$
- C) the system is at equilibrium.
- D)  $\Delta G^\circ > 0$
- E)  $\Delta G^\circ < 0$

Answer: C

## Section 4 (questions 43-56)

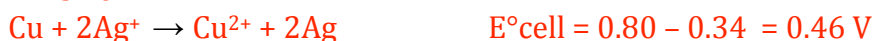
43. Consider an electrochemical cell with a copper ( $\text{Cu}^{2+}$ ) electrode immersed in  $\text{Cu}^{2+}(\text{aq})$  and a silver ( $\text{Ag}^+$ ) electrode immersed in  $\text{Ag}^+(\text{aq})$ .



If  $[\text{Cu}^{2+}]$  is 0.0010 M and  $[\text{Ag}^+]$  is 0.10 M, calculate  $E$ .

- A) 0.40 V
- B) 0.43 V
- C) 0.49 V
- D) 0.52 V
- E) 0.33 V

**\*Answer: B**



$$E = E^\circ_{\text{cell}} - (0.05916/n) \log [\text{Cu}^{2+}]/[\text{Ag}^+]^2$$

$$E = 0.46 - (0.05916/2) \log (0.001/0.01) = 0.46 \text{ V} - 0.03 \text{ V} = 0.43 \text{ V.}$$

44. For the decomposition of nitrous oxide ( $\text{N}_2\text{O}$ ) to  $\text{N}_2$  and  $\text{O}_2$ :

Rate =  $k[\text{N}_2\text{O}]^2$ . Several mechanisms are proposed:

<p>A. <math>\text{N}_2\text{O} \rightarrow \text{N}_2 + \text{O}</math>  <math>\text{N}_2\text{O} + \text{O} \rightarrow \text{N}_2 + \text{O}_2</math></p>	<p>B. <math>\text{N}_2\text{O} \rightarrow \text{N} + \text{NO}</math>  <math>\text{N}_2\text{O} + \text{N} + \text{NO} \rightarrow \text{N}_3 + \text{O}_2</math>  <math>2\text{N}_3 \rightarrow 3\text{N}_2</math></p>
<p>C. <math>2\text{N}_2\text{O} \rightarrow \text{N}_4\text{O}_2</math>  <math>\text{N}_4\text{O}_2 \rightarrow 2\text{N}_2 + \text{O}_2</math></p>	<p>D. <math>3\text{N}_2\text{O} \rightarrow \text{N}_6\text{O}_3</math>  <math>2\text{N}_6\text{O}_3 \rightarrow 6\text{N}_2 + 3\text{O}_2</math></p>

Which of the mechanisms above is most likely to be correct?

- A) Mechanism A.
- B) Mechanism B.
- C) Mechanism C.
- D) Mechanism D.
- E) None of these mechanisms are consistent with the experimental rate law.

**Answer: C**

45. The rate of a reaction can change with

- A) Temperature.
- B) The addition of a catalyst or enzyme.
- C) Reactant concentrations.
- D) Time
- E) All (A-D)

**Answer: E**

46. From the reaction coordinate graph shown here.

- A)  $K = 1$
- B)  $K > 1$
- C)  $K < 1$
- D)  $K < -1$
- E)  $K > -1$

Answer B:

47. A moderately spontaneous reaction, with a small forward driving force

- A) is necessarily a slow forward reaction.
- B) is necessarily a fast forward reaction.
- C) is necessarily a slow reverse reaction.
- D) is necessarily a fast reverse reaction.
- E) None of these are correct

Answer: E. Don't confuse kinetics and thermodynamics. The rate is determined by the activation energy, which might be large or small for a spontaneous reaction.

48. The rate of disappearance of ozone in the reaction  $2\text{O}_3(\text{g}) \rightarrow 3\text{O}_2(\text{g})$  is  $9.0 \times 10^{-3} \text{ atm s}^{-1}$ . What is the rate of appearance of  $\text{O}_2$ ?

- A)  $1.3 \times 10^{-2} \text{ atm s}^{-1}$
- B)  $9.0 \times 10^{-3} \text{ atm s}^{-1}$
- C)  $6.0 \times 10^{-3} \text{ atm s}^{-1}$
- D)  $3.0 \times 10^{-5} \text{ atm s}^{-1}$
- E)  $2.7 \times 10^{-5} \text{ atm s}^{-1}$

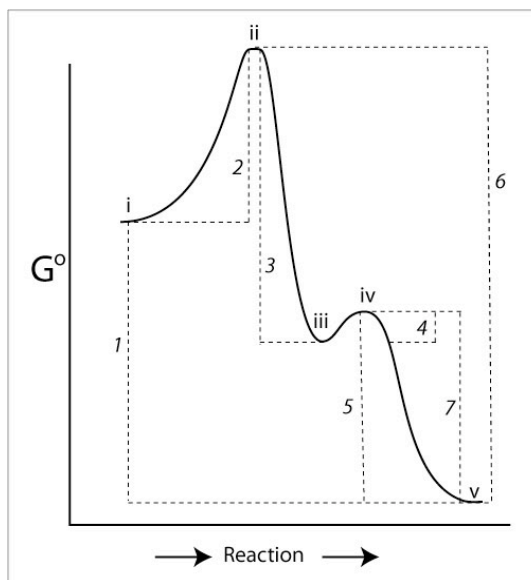
Answer: A

$$(3/2)9.0 \times 10^{-3} = 1.3 \times 10^{-2} \text{ atm/s}$$

49. Which is correct (see graph)

- A) i is the reactant, iii is a transition state, v is the product.
- B) v is the reactant, iv is the first transition state, iii is an intermediate, ii is the second transition state, i is the product.
- C) iii is the reactant, ii is the one transition state, iv is another transition state, i and v are products.
- D) i is the reactant, ii is the first intermediate, iii is the second intermediate, iv is the third intermediate, v is the product.
- E) i is the reactant, ii is the first transition state, iii is the intermediate, iv is the second transition state, v is the product.

Answer: E



50. The following data were obtained for the reaction of NO with O<sub>2</sub>. Concentrations are in M and rates are in M s<sup>-1</sup>.

[NO] <sub>0</sub>	[O <sub>2</sub> ] <sub>0</sub>	Initial Rate
1 × 10 <sup>18</sup>	1 × 10 <sup>18</sup>	2.0 × 10 <sup>16</sup>
2 × 10 <sup>18</sup>	1 × 10 <sup>18</sup>	8.0 × 10 <sup>16</sup>
3 × 10 <sup>18</sup>	1 × 10 <sup>18</sup>	18.0 × 10 <sup>16</sup>
1 × 10 <sup>18</sup>	2 × 10 <sup>18</sup>	4.0 × 10 <sup>16</sup>
1 × 10 <sup>18</sup>	3 × 10 <sup>18</sup>	6.0 × 10 <sup>16</sup>

Which of the following is the rate law for this reaction?

- A) Rate =  $k[\text{NO}][\text{O}_2]$   
 B) Rate =  $k[\text{NO}][\text{O}_2]^2$   
 C) Rate =  $k[\text{NO}]^2[\text{O}_2]$   
 D) Rate =  $k[\text{NO}]^2$   
 E) Rate =  $k[\text{NO}]^2[\text{O}_2]^2$

Answer: C

51. Identify your version (look at the top of the page).

- A) Version A  
 B) Version B  
 C) Version C  
 D) Version D

\*Answer: A (not scored)

52. In the reaction coordinate graph above

- A) 1 is  $\Delta G^\circ_{\text{reaction}}$ , 2 is  $\Delta G^{\ddagger}_{\text{forward first step}}$ , 4 is  $\Delta G^{\ddagger}_{\text{forward second step}}$   
 B) 1 is  $\Delta G^\circ_{\text{reaction}}$ , 2 is  $\Delta G^{\ddagger}_{\text{forward first step}}$ , 7 is  $\Delta G^{\ddagger}_{\text{forward second step}}$   
 C) 1 is  $\Delta G^\circ_{\text{reaction}}$ , 3 is  $\Delta G^{\ddagger}_{\text{forward first step}}$ , 4 is  $\Delta G^{\ddagger}_{\text{forward second step}}$   
 D) 6 is  $\Delta G^\circ_{\text{reaction}}$ , 2 is  $\Delta G^{\ddagger}_{\text{forward first step}}$ , 4 is  $\Delta G^{\ddagger}_{\text{forward second step}}$   
 E) 6 is  $\Delta G^\circ_{\text{reaction}}$ , 1 is  $\Delta G^{\ddagger}_{\text{forward first step}}$ , 5 is  $\Delta G^{\ddagger}_{\text{forward second step}}$

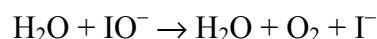
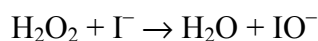
Answer: A

53. From the reaction coordinate graph above

- A)  $k_{\text{reverse second step}} > k_{\text{forward first step}} > k_{\text{forward second step}}$   
 B)  $k_{\text{forward first step}} > k_{\text{forward second step}} > k_{\text{reverse second step}}$   
 C)  $k_{\text{forward second step}} > k_{\text{forward first step}} > k_{\text{reverse first step}}$   
 D)  $k_{\text{forward first step}} > k_{\text{forward second step}} > k_{\text{reverse first step}}$   
 E) Cannot be determined

Answer C:  $k_{\text{forward second step}}$  is greater than all other  $k$  because the  $\Delta G^{\ddagger}$  for that step is smallest, etc.

54. The reaction  $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$  has the following mechanism.



The catalyst in the reaction is:

- A)  $\text{H}_2\text{O}$
- B)  $\text{I}^-$
- C)  $\text{H}_2\text{O}_2$
- D)  $\text{IO}^-$
- E)  $\text{O}_2$

Answer: B

55. A first-order reaction is 42% complete at 17 minutes. Assuming negligible reverse reaction, what is the rate constant?

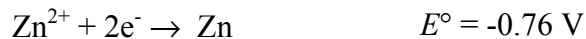
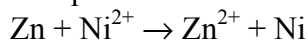
- A)  $3.2 \times 10^{-2} \text{ min}^{-1}$
- B)  $20 \text{ min}^{-1}$
- C)  $31 \text{ min}^{-1}$
- D)  $5.1 \times 10^{-2} \text{ min}^{-1}$
- E)  $0.11 \text{ min}^{-1}$

Answer: D

$$[\text{A}]_t = [\text{A}]_0 e^{-kt}$$

$$k = -\ln[(0.42)](17 \text{ min}) = 0.051 \text{ min}^{-1}$$

56. Determine the equilibrium constant at  $25^\circ\text{C}$  for the reaction



- A)  $8.6 \times 10^{17}$
- B)  $9.3 \times 10^8$
- C)  $4.1 \times 10^3$
- D)  $6.4 \times 10^{-6}$
- E) none of these

Answer: A

$$E^\circ_{\text{cell}} = -0.23 + 0.76 = +0.53 \text{ V}$$

$$\Delta G^\circ = -nFE^\circ = -2(96,485 \text{ J/V})(0.53 \text{ V}) = -102,274 \text{ J/mol}$$

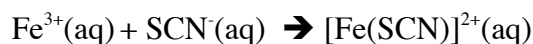
$$\Delta G^\circ = -RT \ln K: K = \exp(-\Delta G^\circ/RT) = \exp(+102,274 \text{ J/mol}/[298\text{K}(8.31 \text{ J/mol-K})]) = 8.6 \times 10^{17}$$



## Section 5 (questions 57-61)

Use the following laboratory information from the Excel table to answer question 57-59.

In lab experiment 8, Determination of  $K_{eq}$ , the equilibrium constant for the formation of iron thiocyanate was calculated by measuring the absorbance of the orange colored product formed after mixing solutions of iron(III) ions and thiocyanate ions as:



Test tubes 1-5 were used to construct a Beer's Law plot,  $A = \epsilon bC$ , for use in calculating  $K_{eq}$  from test tubes 6-12.

	A	B	C	D	E	F	G	H	I
1	<b>Useful Units</b>								
2	Test Tube 1-5 [Fe(NO <sub>3</sub> ) <sub>3</sub> ] <sub>Stock</sub> =		0.0025	Test Tube 1-5 [SCN <sup>-</sup> ] <sub>Stock</sub> =		0.5	Test Tube 6-12 [SCN <sup>-</sup> ] <sub>Stock</sub> =	0.0025	
3	<b>Tabulated Data/Results</b>								
4	Test Tube	Working Fe <sup>3+</sup> (ml)	Stock SCN <sup>-</sup> (ml)	0.1 M HNO <sub>3</sub> (ml)	Total (ml)	[Fe <sup>3+</sup> ] <sub>initial</sub> (M)	[SCN <sup>-</sup> ] <sub>initial</sub> (M)	Absorbance	[Fe(SCN) <sup>2+</sup> ]
5									
6	1	1.0	5.0	4.0				0.100	
7	2	2.0	5.0	3.0				0.200	
8	3	3.0	5.0	2.0				0.250	
9	4	4.0	5.0	1.0				0.320	
10	5	5.0	5.0	0				0.420	
11									
12									
13	Test Tube	Stock Fe <sup>3+</sup> (ml)	Stock SCN <sup>-</sup> (ml)	0.1 M HNO <sub>3</sub> (ml)	Total (ml)	[Fe <sup>3+</sup> ] <sub>initial</sub> (M)	[SCN <sup>-</sup> ] <sub>initial</sub> (M)	Absorbance	[Fe(SCN) <sup>2+</sup> ]
14	6	1.0	1.5	4.5		3.57E-04	3.57E-04	0.120	2.2E-05
15	7	1.0	2.0	4.0		3.57E-04	5.36E-04	0.198	3.3E-05
16	8	1.0	2.5	3.5		3.57E-04	7.14E-04	0.268	4.0E-05
17	9	1.0	3.0	3.0		3.57E-04	8.93E-04	0.324	4.4E-05
18	10	2.0	1.0	4.0		3.57E-04	1.07E-03	0.351	3.0E-05
19	11	2.0	1.5	3.5		7.14E-04	3.57E-04	0.243	4.1E-05
20	12	2.0	2.0	3.0		7.14E-04	5.36E-04	0.330	5.7E-05
21									

57. A working solution was made in a 100 mL volumetric flask by diluting 4.0 mL of iron stock solution to 100 mL to use in test tubes 1-5. Then the working solution was diluted according to the table. What is the initial concentration of iron in cell F7?

- A) 0.50 M
- B) 0.0025 M
- C) 0.0005 M
- D) 0.0001 M
- E) 0.00002 M

Answer: E

58. Write an excel format equation using the cell locations that would be entered to determine the final  $[\text{Fe}^{3+}]$  from test tube 6 after equilibrium was established. (i.e. Excel Equation  $[\text{Fe}^{3+}]_{\text{final}} = \text{A2} * \text{B2} / 2$ )

A)  $[\text{Fe}^{3+}]_{\text{final}} = (\text{I14} * \text{H2}) / 7$

B)  $[\text{Fe}^{3+}]_{\text{final}} = \text{H14} / \text{F14}$

C)  $[\text{Fe}^{3+}]_{\text{final}} = (\text{I14} - \text{F6}) / 7$

D)  $[\text{Fe}^{3+}]_{\text{final}} = \text{F14} - \text{I14}$

E)  $[\text{Fe}^{3+}]_{\text{final}} = \text{G14} - \text{I14}$

Answer: D

59. How did you know the concentration of the product,  $[\text{Fe}(\text{SCN})]^{2+}(\text{aq})$  in test tubes 1-5?

A) I assumed that  $[\text{Fe}(\text{SCN})]^{2+} = [\text{Fe}^{3+}]_{\text{initial}}$

B) I assumed that  $[\text{Fe}(\text{SCN})]^{2+} = [\text{SCN}^-]_{\text{initial}}$

C) I read it off the Absorbance vs. Concentration plot

D) Options A and B

E) None of these

Answer: A

60. In Experiment 10, Applications of Equilibria, you found that your unknown “blood” sample was 0.10 M in acetic acid from the titration analysis (curve). How much 6M NaOH would have to be added to a 100.0 mL sample to make a buffered blood sample with equal moles of HA and A<sup>-</sup> (pH 4.74, assume the volume of NaOH added to be negligible)

A) 0.83 mL

B) 1.7 mL

C) 100.0 mL

D) 2.4 mL

E) I need the  $K_a$  to figure this out

Answer: A

61. In Experiment 11, Calorimetry, Heats of Reactions and Hess’s Law, you made a coffee cup calorimeter and calibrated it before using it to measure heats of reactions. Why did the calorimeter need to be calibrated with hot and cold water?

A) The calorimeter needed to be heated up to the maximum temperature of the reaction

B) The calorimeter absorbed heat and cold unequally

C) All of the heat generated in the reaction was not transferred to the water and thermometer for measurement

D) The calorimeter was a perfect insulator

Answer: C

# PERIODIC TABLE OF THE ELEMENTS

<http://www.kj-soft.com/periodic/>

GROUP	PERIOD																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
IA	IIA	IIIB	IVB	VB	VIB	VII	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H 1.0079 HYDROGEN	2 He 4.0026 HELIUM	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	11 Na 22.990 SODIUM	12 Mg 24.305 MAGNESIUM	13 Al 26.982 ALUMINUM	14 Si 28.086 SILICON	15 P 30.974 PHOSPHORUS	16 S 32.065 SULFUR	17 Cl 35.453 CHLORINE	18 Ar 39.948 ARGON
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 83.796 KRYPTON
37 Rb 85.468 RUBIDIUM	38 Sr 87.62 STRONTIUM	39 Y 88.906 YTRBIUM	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
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 WOLYBDENUM	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
87 Fr 223 FRANCIUM	88 Ra 226 RADIUM	89-103 Ac-Lr Actinide	104 Rf 261 RUFORDIUM	105 Db 262 DUBNIUM	106 Sg 269 SEABORGIUM	107 Bh 264 BOHRIUM	108 Hs 277 HASSIUM	109 Mt 288 MEITNERIUM	110 Uu 281 UNUNNIUM	111 Uu 272 UNUNNIUM	112 Uub 285 UNUNBIUM	113 Uut 284 UNUNTRIUM	114 Uuq 289 UNUNQUADIUM				

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)

Relative atomic mass is shown with the appropriate figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.  
However three such elements (Tl, Pa, and U) are shown with their atomic weights determined by comparison, and for these an atomic weight is tabulated.

Editor: Arjivo Verheijen (arjivo@rednet.com)

LANTHANIDE															
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
57	138.91	140.12	140.91	144.24	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.04	174.97	
ACTINIDE															
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	
89	232.04	231.04	238.03	237	244	243	247	247	251	252	257	258	259	262	

# Physical Constants

## Physical Constants

Constant	Symbol	Value
Atomic Mass Unit	amu	$1.66054 \times 10^{-27}$ kg
Avogadro's Number	N	$6.022 \times 10^{23}$ mol <sup>-1</sup>
Bohr Radius	$a_0$	$5.292 \times 10^{-11}$ m
Boltzmann's constant	k	$1.38066 \times 10^{-23}$ J/K
Charge of an electron	e	$1.60218 \times 10^{-19}$ C
Gas Constant	R	$8.314$ J K <sup>-1</sup> mol <sup>-1</sup> $0.08206$ L atm K <sup>-1</sup> mol <sup>-1</sup>
Mass of an Electron	$m_e$	$9.10939 \times 10^{-31}$ kg
Mass of a Neutron	$m_n$	$1.67493 \times 10^{-27}$ kg
Mass of a Proton	$m_p$	$1.67262 \times 10^{-27}$ kg
Planck's constant	h	$6.62608 \times 10^{-34}$ J s
Speed of Light	c	$2.998 \times 10^8$ m s <sup>-1</sup>
Specific Heat of Water		4.184 J/gC