CCO Problem Set #3 **Date: Jan 1, 2023**

1. 0.27 M NH_3 is at equilibrium with 0.42 M N_2 at 220 °C. What is the equilibrium concentration of H_2 in the reacting mixture? $K_{eq} = 1.8 \times 10^2$ at 220 °C.

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

a) 3.1 M b) 3.6×10^{-3} M c) 9.9×10^{-2} M d) 1.5×10^{-1} M e) 10.0 M

2. 15.0 g of NO_2 (MW = 46.01 g $mole^{-1}$) and 2.0 g of N_2O_4 (MW = 92.01 g mol^{-1}) are at equilibrium in a 1L container at 70 °C. What is the equilibrium constant for the reaction?

$$2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$$

a) 4.9 b) 1.5×10^{-4} c) 6.7×10^{-2} d) 2.0×10^{-1} e) 1.5×10^{2}

3. Consider the following equilibrium:

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$$

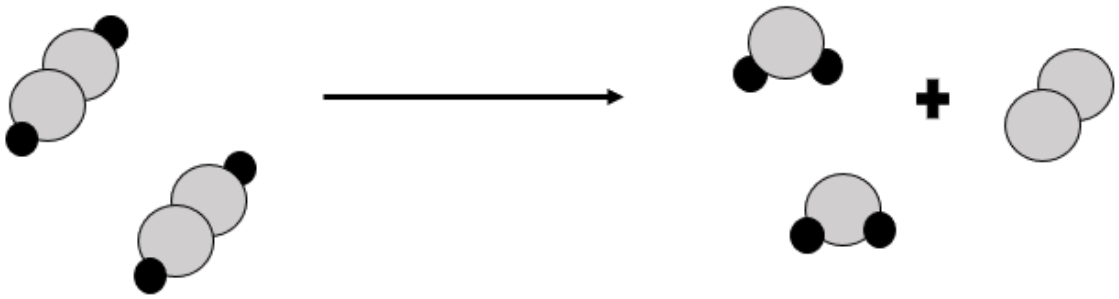
If additional SO_2 is added to the system at equilibrium, what will happen to the % yield of the reaction?

a) Increase because the equilibrium would shift towards the products.
b) Decrease because the equilibrium would shift towards the products.
c) Increase because the equilibrium would shift towards the reactants.
d) Decrease because the equilibrium would shift towards the reactants
e) It would not change

4. A 1.00 L flask contains 1.5 M H_2, 1.5 M Cl_2, and 7.5 M HCl coexisting at equilibrium. 5.0 moles of HCl are removed from the flask. What would be the concentration of each gas when equilibrium is reestablished?

a) 0.79 M H_2, 0.79 M Cl_2, 3.92 M HCl
b) 0.11 M H_2, 0.11 M Cl_2, 5.28 M HCl
c) 1.44 M H_2, 1.44 M Cl_2, 2.62 M HCl
d) 0.67 M H_2, 0.67 M Cl_2, 4.17 M HCl
e) 4.0 M H_2, 4.0 M Cl_2, 2.5 M HCl

5. The following diagram represents a decomposition reaction, at atmospheric pressure and room temperature. A catalyst speeds up the rate of reaction and the temperature of the reaction system rises as the reaction progresses whether a catalyst is used or not.

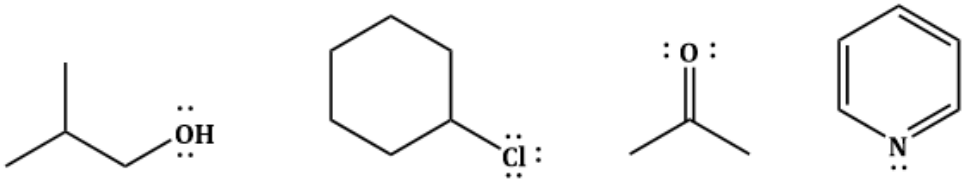


For this reaction, which of the following is TRUE under standard atmospheric conditions?

I) Δ S is positive
II) Δ G is negative
III) Addition of a catalyst changes the reaction intermediates
IV) Raising the temperature increases the spontaneity of the reaction

a) I and II only b) II and III only c) III and IV only d) I and IV only
e) II and IV only f) I, II and III only g) I, III and IV only h) II, III and IV only

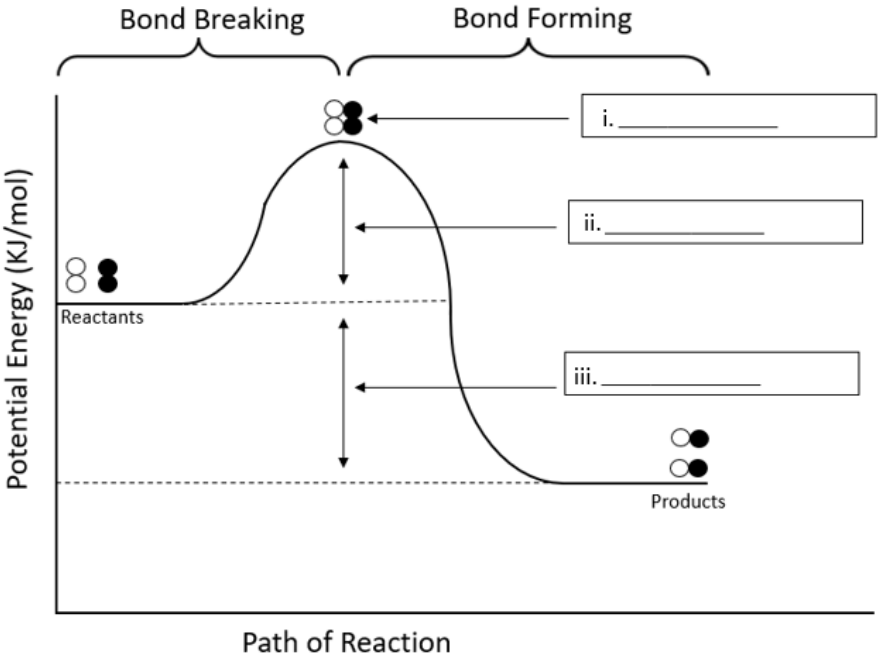
6. Which of the following molecules could act as nucleophiles?



i. ii. iii. iv.

a) i, ii, iii, iv b) ii only c) i, iv d) i, iii, iv e) i only

Use the following diagram to answer question 7.



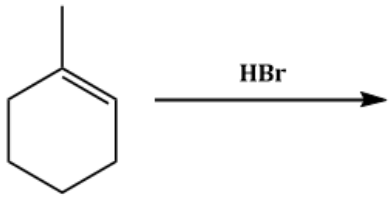
7. Fill in the blanks on the diagram with the correct symbol or term and identify whether the reaction is endothermic or exothermic and if the enthalpy of reaction is positive or negative.

a) i = activated complex, ii = ΔS, iii = E_a (Activation Energy); Exothermic
b) i = ΔS, ii = ΔH, iii = activated complex; Endothermic
c) i = activated complex, ii = ΔH, iii = E_a (Activation Energy); Exothermic
d) i = E_a (Activation Energy), ii = ΔH, iii = ΔS ; Endothermic
e) i = activated complex, ii = E_a (Activation Energy) , iii = ΔH ; Exothermic
f) i = E_a (Activation Energy), ii = ΔS, iii = ΔH ; Endothermic

8. What type or reaction would make 1-propylamine from 1-bromopropane?

a) nucleophilic substitution b) electrophilic addition c) nucleophilic addition
d) rearrangement e) elimination

9. Which of the following is the major organic product produced by the following reaction?



a) 1-methylcyclohex-1-ene
b) 1-bromo-2-methylcyclohexane
c) 1-bromo-1-methylcyclohexane
d) (bromomethyl)cyclohexane
e) 1-bromo-2-methylcyclohex-1-ene

10. When ice at 0 °C melts and becomes liquid water at 0 °C, the heat absorbed is 6.01 kJ mol^{-1}. What is the molar entropy change of fusion (melting) for water at 0 °C?

a) 23.7 J K^{-1} mol^{-1}
b) 20.5 J K^{-1} mol^{-1}
c) 6.01 J K^{-1} mol^{-1}
d) 22.0 J K^{-1} mol^{-1}
e) 21.2 J K^{-1} mol^{-1}

11. Characterize the spontaneity of the following reaction

$$Fe_2O_{3(s)} + 2Al_{(s)} \longrightarrow 2Fe_{(s)} + Al_2O_{3(s)}$$

$\Delta_r H^\circ$ = -851.5 $kmol^{-1}$ and $\Delta_r S^\circ$ = - 375.2 J mol^{-1} K^{-1}.

a) The reaction is always spontaneous
b) The reaction is is never spontaneous
c) The reaction is spontaneous at very low temperatures
d) The reaction is spontaneous a very high temperatures
e) The spontaneity of the reaction cannot be determined from the information provided

12. The following reaction is endothermic. Which of the following statements is TRUE about this reaction?

$$N_{2(g)} + 2O_{2(g)} \longrightarrow 2NO_{2(g)}$$

I) Entropy increases
II) Gibbs free energy is positive
III) The spontaneity of the reaction is temperature dependent

a) I only
b) II only
c) III only
d) I and II only
e) II and III only
f) I and III only
g) I, II and III
h) none of the statements are true

13. Sulfur undergoes a phase transition when heated to a certain temperature. What is the minimum temperature for this reaction to be spontaneous?

$$S_{8\ (rhombic)} \longrightarrow S_{8\ (monoclinic)}$$

Where $\Delta_r H^o$ = 3.213 kJ mol^{-1} and $\Delta_r S^o$ = 8.70 J mol^{-1} K^{-1}

a) 2.71 °C b) 369 °C c) 39.6°C d) 290 °C e) 165 °C

14. At 25 °C with all reactants and products in their standard states (1 bar pressure), the reaction shown below is not spontaneous in the forward direction. Which change could render the reaction spontaneous in the forward direction?

$$COCl_{2(g)} \longrightarrow CO_{(g)} + Cl_{2(g)}$$

a) Lowering the temperature
b) Raising the temperature
c) Remove some of the reactants
d) Remove some of the products
e) Two of the options provided would increase the spontaneity of the reaction

15. Calcite is a mineral that decomposes according to the equation:

$$CaCO_{3(s)} \longrightarrow CaO_{(s)} + CO_{2(g)}$$

Where $\Delta_r H^o$ = 178.3 kJ mol^{-1} and $\Delta_r S^o$ = 160.6 J mol^{-1} K^{-1}.
Calculate ΔG^o at 800 °C.

a) 5976 J mol^{-1} b) 49820 J mol^{-1} c) -172145 J mol^{-1}
d) -49820 J mol^{-1} e) 136870 J mol^{-1}

16. A 50 g strip of copper, originally at 20°C is introduced into a calorimeter at with 150 mL of water initially at 85°C. If the contents and the calorimeter form a closed system, which of the following is a TRUE statement of the entropy in the system as it reaches equilibrium?

a) The entropy of the copper increases while the entropy of the water decreases and the total entropy of the system stays the same.
b) The entropy of copper decreases while the entropy of the water increases and the total entropy of the system stays the same
c) The entropy of the copper and the water increase as does the entropy of the system.
d) The total entropy of the system increases
e) The total entropy of the system decreases

17. In low concentrations, phosgene is a pale-yellow gas with a pleasant odor resembling that of fresh cut hay. In higher concentrations, phosgene becomes very toxic; so much so that armies used it to kill hundreds of people during the first world war. Phosgene ($COCl_2$) is formed from the combination of chlorine gas and carbon monoxide. Calculate $\Delta_r S^o$ given that $\Delta_r H^o$ = -220 kJ mol^{-1} and $\Delta_r G^o$ = -206 kJ mol^{-1} At 25.0 °C.

a) 51.3 J mol^{-1} K^{-1} b) -560 J mol^{-1} K^{-1} c) 47.0 J mol^{-1} K^{-1}
d) -51.3 J mol^{-1} K^{-1} e) -47.0 J mol^{-1} K^{-1}

18. Assign oxidation numbers for each atom in the following species: $Pb(NO_3)_2$ (Answer order: Pb, N, O)

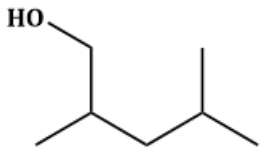
a) +2, +6, -2 b) +2 , +5, -2 c) +1 , +5, -2 d) +2, -5, +2 e) +1, +3, -1

19. In order, what are the oxidizing agent and the reducing agent in reaction:

$$5CO_{(g)} + Cl_2O_{5(s)} \longrightarrow 5CO_{2(g)} + Cl_{2(g)}$$

a) CO and Cl_2O_5 b) Cl_2O_5 and Cl_2 c) CO_2 and Cl_2O_5
d) Cl_2 and CO_2 e) CO_2 and CO

20. How many unique ^1H NMR signals would you expect to observe for the following molecule:



a) 5 b) 6 c) 7 d) 8 e) 9

21. A standard Zn^{2+}/Ni^{2+} cell is adjusted by the addition of Ni(II) ions to increase their concentration from 1.0 M to 3.5 M. Calculate the new voltage of the cell after this addition.

a) 0.53 V b) 0.54 V c) 0.55 V d) 0.56 V e) 0.57 V

22. Determine which of the following equations refer to spontaneous redox reactions. Assume that every species listed is in its standard state and the temperature is 25 °C.

i) $Ni^{2+}_{(aq)} + H_{2(g)} \longrightarrow Ni_{(s)} + 2H^{+}_{(aq)}$

ii) $Fe^{3+}_{(aq)} + 2I^{-}_{(aq)} \longrightarrow Fe^{2+}_{(aq)} + I_{2(s)}$

iii) $2Br^{-}_{(aq)} + Cl_{2(g)} \longrightarrow Br_{2(l)} + 2Cl^{-}_{(aq)}$

iv) $2Cr^{3+}_{(aq)} + 6Fe^{3+}_{(aq)} + 7H_2O_{(l)} \longrightarrow Cr_2O_7^{2-}{}_{(aq)} + 6Fe^{2+}_{(aq)} + 14H^{+}_{(aq)}$

a) i and iv b) ii and iii c) i, ii, iii, and iv d) None of the reactions e) ii, iii, iv

23. Which of the following elements is the best reducing agent?

a) $Al_{(s)}$ b) $Ni_{(s)}$ c) $Cu_{(s)}$ d) $Au_{(s)}$ e) $F_{2\,(g)}$

24. One half cell in a voltaic cell at 25 °C is constructed from silver wire dipped into a 0.35 M $AgNO_3$ solution. The other half-cell consists of a zinc electrode in a 0.015 M $Zn(NO_3)_2$ solution. Calculate the electromotive force (emf) of the cell.

a) 1.536 V b) 1.561 V c) 1.587 V d) 1.628 V e) 1.482 V

25. Consider an electrochemical cell at 25 °C based on the following half-reactions:

$$Ni^{2+}_{(aq)} + 2e^{-} \longrightarrow Ni_{(s)}$$

$$Cd^{2+}_{(aq)} + 2e^{-} \longrightarrow Cd_{(s)}$$

In both cases the concentration of Ni^{2+} and Cd^{2+} ions are both 1 M. Calculate the equilibrium constant, K, for this process at 25 °C.

a) 3.4×10^5 b) 2.6×10^4 c) 7.4×10^2 d) 1.6×10^2 e) 5.5×10^5

Supporting Information

Type	$\Delta_r S^\circ$	$\Delta_r H^\circ$	Spontaneity
1	$\Delta_r S^\circ > 0$	$\Delta_r H^\circ < 0$ ($\Delta S^\circ_{surr} > 0$)	Spontaneous. $\Delta S^\circ_{univ} > 0$
2	$\Delta_r S^\circ < 0$	$\Delta_r H^\circ < 0$ ($\Delta S^\circ_{surr} > 0$)	Depends on relative magnitude of $\Delta_r S^\circ$ and $\Delta_r H^\circ$
3	$\Delta_r S^\circ > 0$	$\Delta_r H^\circ > 0$ ($\Delta S^\circ_{surr} < 0$)	Depends on relative magnitude of $\Delta_r S^\circ$ and $\Delta_r H^\circ$
4	$\Delta_r S^\circ < 0$	$\Delta_r H^\circ > 0$ ($\Delta S^\circ_{surr} < 0$)	Not Spontaneous. $\Delta S^\circ_{univ} < 0$

Standard Reduction Potentials at 25°C (298 K) for Many Common Half-reactions

Half-reaction	$\mathscr{E}^\circ$ (V)	Half-reaction	$\mathscr{E}^\circ$ (V)
$F_2 + 2e^- \rightarrow 2F^-$	2.87	$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$	0.40
$Ag^{2+} + e^- \rightarrow Ag^+$	1.99	$Cu^{2+} + 2e^- \rightarrow Cu$	0.34
$Co^{3+} + e^- \rightarrow Co^{2+}$	1.82	$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$	0.27
$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$	1.78	$AgCl + e^- \rightarrow Ag + Cl^-$	0.22
$Ce^{4+} + e^- \rightarrow Ce^{3+}$	1.70	$SO_4^{2-} + 4H^+ + 2e^- \rightarrow H_2SO_3 + H_2O$	0.20
$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$	1.69	$Cu^{2+} + e^- \rightarrow Cu^+$	0.16
$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$	1.68	$2H^+ + 2e^- \rightarrow H_2$	0.00
$IO_4^- + 2H^+ + 2e^- \rightarrow IO_3^- + H_2O$	1.60	$Fe^{3+} + 3e^- \rightarrow Fe$	−0.036
$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$	1.51	$Pb^{2+} + 2e^- \rightarrow Pb$	−0.13
$Au^{3+} + 3e^- \rightarrow Au$	1.50	$Sn^{2+} + 2e^- \rightarrow Sn$	−0.14
$PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O$	1.46	$Ni^{2+} + 2e^- \rightarrow Ni$	−0.23
$Cl_2 + 2e^- \rightarrow 2Cl^-$	1.36	$PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$	−0.35
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$	1.33	$Cd^{2+} + 2e^- \rightarrow Cd$	−0.40
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1.23	$Fe^{2+} + 2e^- \rightarrow Fe$	−0.44
$MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$	1.21	$Cr^{3+} + e^- \rightarrow Cr^{2+}$	−0.50
$IO_3^- + 6H^+ + 5e^- \rightarrow \frac{1}{2}I_2 + 3H_2O$	1.20	$Cr^{3+} + 3e^- \rightarrow Cr$	−0.73
$Br_2 + 2e^- \rightarrow 2Br^-$	1.09	$Zn^{2+} + 2e^- \rightarrow Zn$	−0.76
$VO_2^+ + 2H^+ + e^- \rightarrow VO^{2+} + H_2O$	1.00	$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$	−0.83
$AuCl_4^- + 3e^- \rightarrow Au + 4Cl^-$	0.99	$Mn^{2+} + 2e^- \rightarrow Mn$	−1.18
$NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$	0.96	$Al^{3+} + 3e^- \rightarrow Al$	−1.66
$ClO_2 + e^- \rightarrow ClO_2^-$	0.954	$H_2 + 2e^- \rightarrow 2H^-$	−2.23
$2Hg^{2+} + 2e^- \rightarrow Hg_2^{2+}$	0.91	$Mg^{2+} + 2e^- \rightarrow Mg$	−2.37
$Ag^+ + e^- \rightarrow Ag$	0.80	$La^{3+} + 3e^- \rightarrow La$	−2.37
$Hg_2^{2+} + 2e^- \rightarrow 2Hg$	0.80	$Na^+ + e^- \rightarrow Na$	−2.71
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	0.77	$Ca^{2+} + 2e^- \rightarrow Ca$	−2.76
$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2$	0.68	$Ba^{2+} + 2e^- \rightarrow Ba$	−2.90
$MnO_4^- + e^- \rightarrow MnO_4^{2-}$	0.56	$K^+ + e^- \rightarrow K$	−2.92
$I_2 + 2e^- \rightarrow 2I^-$	0.54	$Li^+ + e^- \rightarrow Li$	−3.05
$Cu^+ + e^- \rightarrow Cu$	0.52		

Useful Formulas:

$$E = E\circ \ - \left(\frac{0.0592}{n}\right) log\ (Q)\ ,\ (where\ Q = K\ at\ equlibrium)$$

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta S = \frac{q}{T}$$