CHM 106
Final Exam

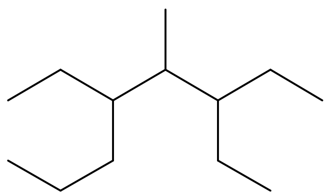
1. Sulfuric acid has $pK_{a2} = 1.99$. Suppose you have a solution that has $[HSO_4^-] = 2.50$ M and $[SO_4^{2-}] = 4.00$ M.

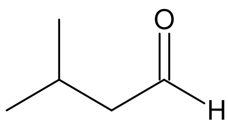
a) What is the pH of this solution?

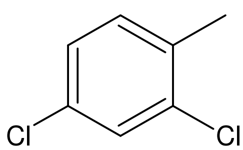
b) Suppose 15.0 g KOH(*s*) is added to 1.00 L of this solution. What is the new pH of the solution?

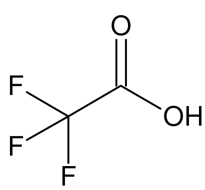
c) What chemical behavior does this solution exhibit?

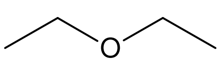
2. Give an unambiguous, systematic name for each compound:

a) 

b) 

c) 

d) 

e) 

3. Hydrocyanic acid (HCN) is a weak acid with $K_a = 6.17 \times 10^{-10}$. Suppose a 20.00 mL sample of 0.100 M hydrocyanic acid is titrated with 0.100 M KOH.

a) What is the pH of the HCN solution before any base is added?

b) What is the pH after 10.00 mL of KOH is added?

c) What is the pH at the equivalence point?

d) What is the pH after 40.00 mL of KOH is added?

e) Sketch a titration curve for this titration. On your curve, lable the points calculated above.

f) If the indicators methyl orange (pK_a = 3.3), bromothymol blue (pK_a = 7.1), and thymolphthalein (pK_a = 10.0) were available, which one would you use for the titration? Explain.

4. Using line-angle notation or a structural formula, draw the structure of each compound:

a) 1,2-cyclopentanediol

b) *cis*-2-bromo-3-hexene

c) triethylamine

d) phenyl propanoate

e) 4-methyl-2-pentanone

5. Carbon-14 is an unstable nuclide with a half life of 5,730 years.

a) Carbon-14 undergoes beta decay. Write a balanced nuclear equation for this process.

b) The rate of decay of ^{14}C is directly proportional to the amount of ^{14}C present. What order is this kinetic process?

c) An antique dealer presents a piece of wooden furniture he claims is from about 1200 AD. The furniture displays an activity (proportional to amount) of 12.35 counts/min. If the activity of freshly cut wood is 13.60 counts/min, then is the dealer correct in his claim of the age of the furniture? If not, how old is the furniture?

6. Salicylic acid ($H_2C_7H_5O_3$) is a weak diprotic acid with $K_{a1} = 1.05x10^{-3}$ and $K_{a2} = 4.17x10^{-13}$.

a) Write balanced chemical equations for the stepwise dissociation of salicylic acid.

b) Write equilibrium expressions for these dissociations.

c) What is the pH of a 0.02 M salicylic acid solution?

d) What is the concentration of the salicylate ($C_7H_5O_3^{2-}$) anion?

7. In the gas phase, carbon monoxide and hydrogen gas are in equilibrium with methanol:

$$CO(g) + 2\ H_2(g) \rightleftharpoons CH_3OH(g)$$

a) Write an equilibrium expression for this reaction using partial pressures.

b) If the partial pressures of all species are 1 atm, what is the value of the reaction quotient?

c) At 500K, the equilibrium constant for this reaction is 387. Which direction does the system need to shift to reach equilibrium?

d) What are the equilibrium partial pressures of all species?

e) What is the value of ΔG for this reaction at 500K when the system is at equilibrium?

8. Manganese (IV) oxide reacts with iodide to produce manganese (II) and iodine in the following unbalanced equation:

$$\mathrm{MnO_2}(s) + \mathrm{I^-}(aq) \rightarrow \mathrm{Mn^{2+}}(aq) + \mathrm{I_2}(aq)$$

a) Assign oxidation states to all atoms involved in this reaction.

b) Identify which atom is being oxidized and which atom is being reduced.

c) Identify the oxidizing agent and the reducing agent.

d) Using the method of half-reactions, write a balanced chemical equation for this reaction.

e) What is the standard cell potential for this reaction?

f) Is this reaction spontaneous?

g) What is ΔG^0 for this reaction?

h) What is the value of the equilibrium constant for this reaction?

i) Sketch an electrochemical cell for this process. In your sketch, identify the anode, the cathode, and the direction of electron flow.

j) Write the line notation shorthand for this cell.

k) If 0.500 mol of I^-(*aq*) is consumed during the operation of this cell, how many Coulombs of charge pass through the wire?

l) If the discharge in part k occurs over 2.00 hour, how many amperes of current flows through the wire?

9. The Cativa process is a modern method of synthesizing ethanoic acid from methanol and carbon monoxide under iridium (I) and iodide catalysis:

$$CH_3OH(l) + CO(g) \xrightarrow{Ir^+(aq),\, I^-(aq)} CH_3COOH(aq)$$

For this process, initial rate data was acquired:

$[Ir^+]$ (mol / L)	$[I^-]$ (mol / L)	CH_3OH (mol / L)	CO (mol / L)	rate (mol / L · hr)
0.0017	0.53	1.00	0.13	21.3
0.0051	0.53	1.00	0.13	63.9
0.0017	1.06	1.00	0.13	42.6
0.0017	1.06	2.00	0.13	42.6
0.0017	1.06	1.00	0.26	85.2

a) What is the differential rate law?

b) What is the value of the rate constant?

c) It is possible to run this reaction under conditions where water is present in small enough amounts that it is not the solvent. Under these conditions, doubling the concentration of water will cause a halving in the reaction rate. What is the order of the reaction with respect to water under these conditions?

For the remaining questions, circle the letter that best answers the question.

10. How many neutrons, protons, and electrons are in tungsten-184?

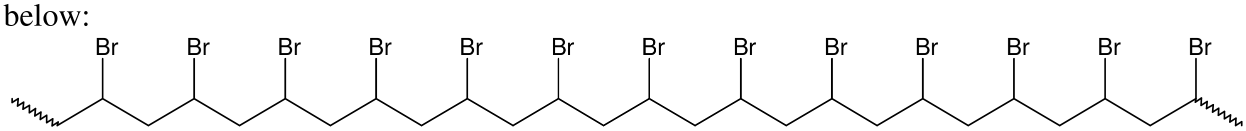
(A) 110 neutrons, 74 protons, 110 electrons
(B) 74 neutrons, 184 protons, 184 electrons
(C) 184 neutrons, 74 protons, 74 electrons
(D) 110 neutrons, 74 protons, 74 electrons
(E) 110 neutrons, 74 protons, 184 electrons

11. Which of the following statements are *false*?

I. The strength of an acid is directly proportional to the affinity of the conjugate base for hydrogen ions
II. A weak acid has a strong conjugate base
III. As base strength increases, the conjugate acid is less willing to donate hydrogen ions.
IV. The dissociation equilibrium for a strong acid lies to the right.

(A) **II** and **IV**
(B) **I**, **II**, and **IV**
(C) **II** only
(D) **I** and **II**
(E) none of the above

12. Poly(vinyl bromide) is sometimes used for plumbing chemistry labs because the material has a relatively high resistance to common laboratory reagents. A section of PVB polymer is shown below:



Which of the following statements are *true*?

I. The polymer can be represented as $[CH_2CHBr]_n$.
II. The polymer can be represented as $[CHBrCH_2CHBr]_n$.
III. The monomer of this polymer is bromoethane.
IV. The monomer of this polymer is bromoethene.
V. The monomer of this polymer is bromoethyne.

(A) **II** and **III**
(B) **I** and **IV**
(C) **I** and **III**
(D) **II** and **V**
(E) **I** and **V**

13. Solution A has a pH of 3.00 and solution B has a pH of 4.00. Which of the following statements are *false*?

I. Solution B has ten times as many OH^- ions as solution A.
II. Solution B has ten times as many H_3O^+ ions as solution A.
III. Solution A has ten times as many H_3O^+ ions as solution B.
IV. There are no OH^- ions in either solution because they are both acidic.

(A) **I** and **IV**
(B) **I** and **III**
(C) **III** and **IV**
(D) **IV** only
(E) **II** and **IV**

14. Addition of a neutron to thorium-233 can induce fission to strontium-89, tellurium-141, and another particle(s):

$$^{1}_{0}n + ^{233}_{90}Th \rightarrow ^{89}_{38}Sr + ^{141}_{52}Te + ?$$

What is the other particle(s)?

(A) $^{4}_{2}He$
(B) $3\ ^{1}_{0}n$
(C) $4\ ^{1}_{0}n$
(D) $4\ ^{1}_{1}p$
(E) $^{3}_{2}He$

15. Consider the vaporization of mercury, which occurs at 356.5 °C:

$$Hg(l) \rightarrow Hg(g)$$

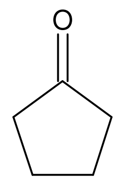
Which of the following statements are *true*?

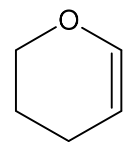
I. $\Delta S_{system} > 0$ because a gas has greater positional entropy than a liquid.
II. $\Delta S_{system} < 0$ because a gas uniformly filling its container is more ordered than a liquid.
III. $\Delta S_{surroundings} > 0$ because the process is exothermic.
IV. $\Delta S_{surroundings} < 0$ because the process is endothermic.
V. $\Delta S_{universe} > 0$ for all temperatures less than 356.5 °C.

(A) **I** and **III**
(B) **II** and **III**
(C) **I**, **IV**, and **V**
(D) **V** only
(E) **I** and **IV**

For 16 - 19, circle whether the pair of molecules shown are not isomers, structural isomers (same formula, different structure), geometric (cis / trans) isomers, or optical isomers.

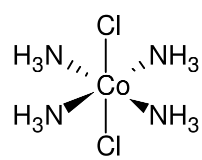
16.

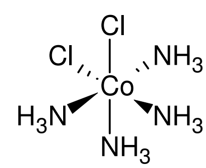




(A) Not isomers
(B) Structural isomers
(C) Geometric isomers
(D) Optical isomers

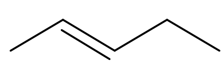
17.

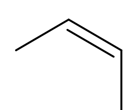




(A) Not isomers
(B) Structural isomers
(C) Geometric isomers
(D) Optical isomers

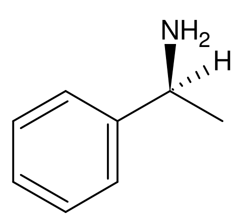
18.

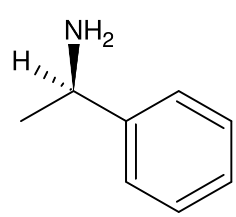




(A) Not isomers
(B) Structural isomers
(C) Geometric isomers
(D) Optical isomers

19.

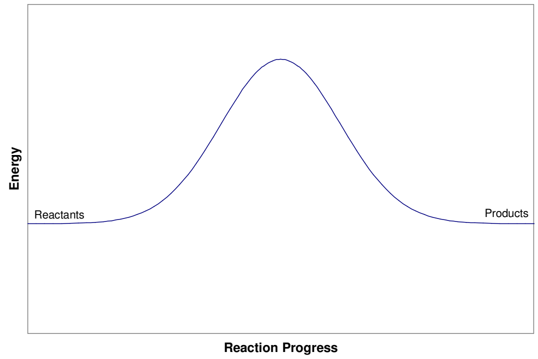




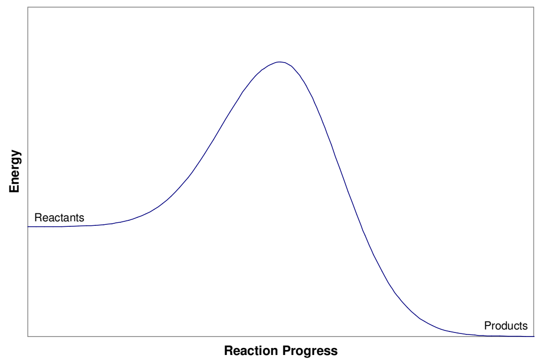
(A) Not isomers
(B) Structural isomers
(C) Geometric isomers
(D) Optical isomers

20. The reaction progress diagrams for several reactions are given:

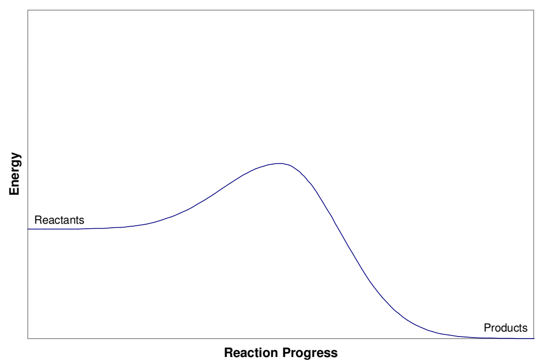
Reaction A:



Reaction B:



Reaction C:



Which of the following statements are *true*?

I. Reaction B and reaction C have the same activation energy.
II. Reaction C will react faster than reaction A or reaction B.
III. Reaction B may be the same as reaction A, but with a catalyst added.
IV. Reaction C may be the same as reaction B, but with a catalyst added.

(A) **II** only
(B) **I** and **III**
(C) **I** and **IV**
(D) **II** and **IV**
(E) all of the above

For questions 21 - 25, refer to the following table of acid and base dissociation constants and circle the letter that best describes the acid/base properties of each of the following salts.

Substance	K_a	K_b
HCN	6.17×10^{-10}	
$HC_2H_3O_2$	1.78×10^{-5}	
C_5H_5N		1.49×10^{-9}
NH_3		1.78×10^{-5}

21. $NaC_2H_3O_2$

(A) produces an acidic solution when dissolved in water
(B) produces a basic solution when dissolved in water
(C) produces a neutral solution when dissolved in water

22. NH_4CN

(A) produces an acidic solution when dissolved in water
(B) produces a basic solution when dissolved in water
(C) produces a neutral solution when dissolved in water

23. C_5H_5NHCl

(A) produces an acidic solution when dissolved in water
(B) produces a basic solution when dissolved in water
(C) produces a neutral solution when dissolved in water

24. KCl

(A) produces an acidic solution when dissolved in water
(B) produces a basic solution when dissolved in water
(C) produces a neutral solution when dissolved in water

25. $NH_4C_2H_3O_2$

(A) produces an acidic solution when dissolved in water
(B) produces a basic solution when dissolved in water
(C) produces a neutral solution when dissolved in water

26. Suppose the system $Zn(s) \mid Zn^{2+}(aq) \parallel Cu^{2+}(aq) \mid Cu(s)$ is to be utilized as a galvanic cell. Which of the following statements are *true*?

I. Copper is the anode and zinc is the cathode.
II. Electrons will flow from the zinc electrode through the wire to the copper electrode.
III. The reaction will be spontaneous when zinc is oxidized and copper (II) is reduced.
IV. The cell potential $\mathscr{E}^0$ can be increased by increasing concentration of $[Zn^{2+}]$.
V. The cell potential $\mathscr{E}^0$ will be at a minimum when the system reaches equilibrium.

(A) **II**, **III**, and **V**
(B) **II**, **III**, and **IV**
(C) **I**, **II**, and **V**
(D) **I**, **III**, and **IV**
(E) **I** and **IV**

For the problems 27 - 30, consider the following disturbances to systems at equilibrium and predict the nature of the shift in equilibrium position.

27. $CaCO_3(s)$ is added to the system $CaCO_3(s) \rightleftharpoons CaO(s) + O_2(g)$.

(A) The equilibrium will shift left.
(B) The equilibrium will shift right.
(C) The equilibrium position will not change.

28. The partial pressure of $H_2(g)$ is increased in the system $N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$.

(A) The equilibrium will shift left.
(B) The equilibrium will shift right.
(C) The equilibrium position will not change.

29. The total pressure is increased on the system $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$.

(A) The equilibrium will shift left.
(B) The equilibrium will shift right.
(C) The equilibrium position will not change.

30. The exothermic reaction in the system $C_2H_2N_4(g) \rightleftharpoons 2\ N_2(g) + C_2H_2(g)$ is heated.

(A) The equilibrium will shift left.
(B) The equilibrium will shift right.
(C) The equilibrium position will not change.

31. The reduction potential of the reaction $Sn^{2+}(aq) + 2\,Fe^{2+}(aq) \rightarrow Sn(s) + 2\,Fe^{3+}(aq)$ is:

(A) 0.91 V
(B) 0.63 V
(C) 0.28 V
(D) -0.63 V
(E) -0.91 V

32. A buffer solution of pH = 3.4 is desired. If the following reagents are available, which pair of reagents will make the buffer with the highest capacity?

(A) HNO_3 (pK_a = -1.37) and KNO_3
(B) NaH_2PO_3 (pK_a = 6.68) and Na_2HPO_3
(C) HOCN (pK_a = 3.46) and KCl
(D) K_2HPO_4 (pK_a = 11.90) and K_3PO_4
(E) HF (pK_a = 3.20) and NaF

Half-Reaction	$\mathscr{E}°$ (V)	Half-Reaction	$\mathscr{E}°$ (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	$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$	0.34
$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$	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
$2e^- + 2H^+ + IO_4^- \rightarrow IO_3^- + H_2O$	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		

Equations and Constants

$PV = nRT$

$$\ln k = -\frac{E_a}{R}\frac{1}{T} + \ln A$$

$\ln [A] = -kt + \ln [A]_0$

$$\ln \frac{k_1}{k_2} = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\frac{1}{[A]} = kt + \frac{1}{[A]_0}$$

$ax^2 + bx + c = 0$

$[A] = -kt + [A]_0$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$K_p = K(RT)^{\Delta n}$

$K_w = 1.00 \times 10^{-14} = [H^+][OH^-]$

$pH = -\log [H^+]$

$pH + pOH = 14.00$

$pOH = -\log [OH^-]$

$K_a \cdot K_b = K_w$

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

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

$\Delta G = \sum n_p \cdot \Delta G_p - \sum n_r \cdot \Delta G_r$

$\Delta G = \Delta G^0 + RT \ln Q$

$\Delta G^0 = -nF\mathscr{E}^0$

$\Delta G^0 = -RT \ln K$

$$\mathscr{E} = \mathscr{E}^0 - \frac{RT}{nF}\ln Q$$

$$\ln\left(\frac{N}{N_0}\right) = -kt$$

$$k = \frac{\ln 2}{t_{1/2}}$$

$R = 8.314\ J / mol \cdot K = 0.0821\ L \cdot atm / mol \cdot K$

$F = 96{,}485\ C / mol\ e^-$

mass of proton = 1.67262×10^{-24} g

mass of neutron = 1.67493×10^{-24} g

mass of electron = 9.10929×10^{-28} g

$c = 3.00 \times 10^8$ m / s