CHM 106
Final Exam

1. Draw the structure for each compound.

a) 1,3-cyclopentadiene

b) 2-methylpropanal

c) 2,6-diaminohexanoic acid

d) dibutyl ether

e) *trans*-1-bromo-2-butene

2. The zinc-mercuric oxide cell is an obsolete battery technology that was used in small electrical devices such as hearing aids and cameras prior to environmental concerns about mercury toxicity. The following half-reactions occur in the zinc-mercuric oxide cell:

Half-reaction	$\mathcal{E}°$
$HgO(s) + H_2O(l) + 2\ e^- \rightarrow Hg(l) + 2\ OH^-(aq)$	0.0977
$ZnO(s) + H_2O(l) + 2\ e^- \rightarrow Zn(s) + 2\ OH^-(aq)$	-1.260

a) What is the balanced chemical equation and the standard cell potential $\mathcal{E}°$ for this cell?

b) What is the anode and cathode in this cell?

c) What is the line notation for this cell?

d) Suppose you want to use this cell to power a light emitting diode (LED), which will only glow when current passes through it in the correct direction. LEDs have a short wire and a long wire; in order for the LED to light, electrons must flow into the short wire and out of the long wire. To which electrodes must you connect the wires on the LED to get light?

e) Suppose that a particular cell contains 0.15 g of $HgO(s)$ as the limiting reagent. If the LED consumes a constant 0.010 A of current at the standard cell potential, how long will this battery power the LED before it goes flat?

3. When uranium-235 reacts with a neutron, it undergoes nuclear fission to produce barium-140 and krypton-93.

a) Write a balanced nuclear equation for this process. How many neutrons are produced?

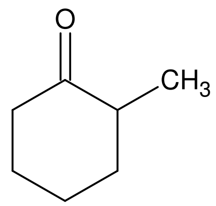
b) What is the change in mass when 1.0 mol of uranium-235 undergoes this fission process? The exact masses of these particles are given below:

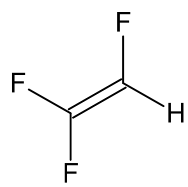
Particle	Mass (g / mol)
^{235}U	235.043 924
^{140}Ba	139.910 581
^{93}Kr	92.931 130
$^{1}_{0}n$	1.008 665

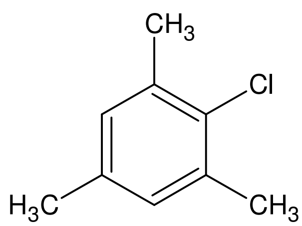
c) How much energy is liberated when 1.0 mol of uranium-235 undergoes fission?

d) In the year 2000, the state of Indiana burned 5.35×10^{10} kg of coal to generate 1.28×10^{11} kW-hr of energy (as electricity). What mass of uranium-235 (in kg) would be necessary to supply this amount of energy? There are 3.6×10^{6} J / kW-hr.

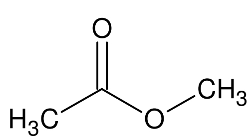
4. Provide unambiguous, systematic names for the following compounds:

a) 

b) 

c) 

d) $(CH_3)_3COH$

e) 

5. For the following reaction, initial rate data was obtained and is shown below:

$$BrO_3^-(aq) + 5\,Br^-(aq) + 6\,H^+(aq) \rightarrow 3\,Br_2(l) + 3\,H_2O(l)$$

$[BrO_3^-]$ (mol / L)	$[Br^-]$ (mol / L)	$[H^+]$ (mol / L)	Initial rate (mol / L · s)
0.10	0.10	0.10	1.2×10^{-3}
0.20	0.10	0.10	2.4×10^{-3}
0.20	0.30	0.10	7.4×10^{-3}
0.20	0.10	0.20	9.6×10^{-3}

a) What is the differential rate law?

b) What is the value of the rate constant?

c) The following mechanism has been proposed for this reaction:

$2\,H^+ + BrO_3^- + 2\,Br^- \rightarrow BrO_2^- + H_2O + Br_2$	slow
$2\,H^+ + BrO_2^- + 2\,Br^- \rightarrow BrO^- + H_2O + Br_2$	fast
$2\,H^+ + BrO^- + Br^- \rightarrow Br_2 + H_2O$	fast

Is this mechanism consistent with kinetic data? Explain.

6. Ammonia is a weak base with $K_b = 1.76\times10^{-5}$. Concentrated ammonia solution is 14.53 M.

a) Suppose that an ammonia solution is prepared by diluting 413 mL of concentrated ammonia to 1.00 L. What is the concentration of this solution?

b) What is the pH of this solution?

c) Suppose that 1.0 mol of HCl(*g*) is added to the solution from part (a). What is the new pH?

d) Suppose that 15.0 g of NaOH(*s*) is added to the solution from part (c). What is the new pH?

e) What chemical behavior does the solution from part (c) exhibit?

7. Hydrazine reacts with dinitrogen tetroxide to form nitrogen gas and water:

$$2\ N_2H_4(l) + N_2O_4(l) \rightarrow 3\ N_2(g) + 4\ H_2O(g)$$

This combination is sometimes used as a propellant in space exploration due to the fact that the two reactants ignite spontaneously upon mixing. Thermodynamic data for these substances are given below:

Substance	ΔH_f^0 (kJ / mol)	S^0 (J / mol · K)
$N_2H_4(l)$	-19.5	209.2
$N_2O_4(l)$	50.6	121.2
$N_2(g)$	0	191.6
$H_2O(g)$	-241.8	188.8

a) Qualtitatively, what should the signs of ΔH^0 and ΔS^0 be for this reaction? Explain.

b) What is the value of ΔH^0 for this reaction?

c) What is the value of ΔS^0 for this reaction?

d) Suppose this reaction runs at 3000 K. What is the value of ΔG?

e) What is the value of the equilibrium constant at 3000 K?

8. Explain the following phenomena:

a) A properly named alkane will never have a methyl substituent on carbon 1.

b) The process for converting diamond to graphite is exergonic, but diamond is indefinitely stable under standard conditions.

c) The mass of a nucleus of $^{12}_{6}C$ weighs 0.0956 g/mol less than the equivalent amount of protons and neutrons.

d) A solution that is 1.0 M in acetic acid and 1.0 M in sodium acetate resists changes in pH when small amounts of acid or base are added, but a solution that is 1.0 M in hydrochloric acid and 1.0 M in sodium chloride does not.

e) The half-life of tritium ($^{3}_{1}H$) is 12.3 years, but significant amounts of tritium still exist after 24.6 years (two half-lives) have elapsed.

9. Butanoic acid is a weak acid with $K_a = 1.52 \times 10^{-5}$. Suppose that a 10.00 mL aliquot of 1.00 M butanoic acid is titrated with standard 1.00 M sodium hydroxide.

a) What is the pH of the butanoic acid solution before and base is added?

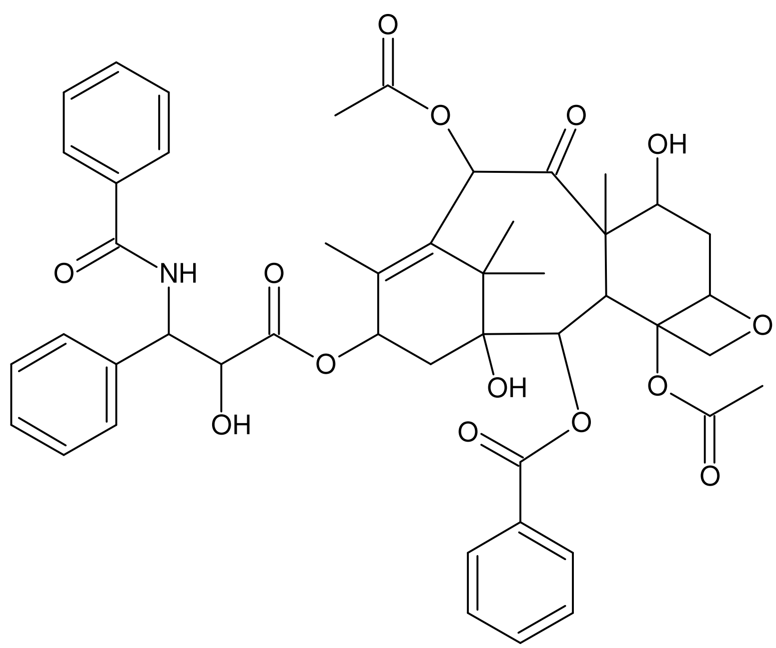
b) What is the pH after 5.00 mL of NaOH is added?

c) What is the pH at the equivalence point?

d) What is the pH after 20.00 mL of NaOH is added?

e) Sketch the titration curve for this titration. In your sketch, identify the following points: (1) pH depends only on a weak acid, (2) pH depends only on the conjugate base, (3) pH depends only on the strong base hydroxide, (4) the equivalence point, (5) pH = pK_a, (6) the buffer region.

10. The compound taxol, shown below, is important in cancer research and treatment. Circle as many functional groups as you can find, and label what kind of functional group they are.



Taxol

For the remaining questions, circle the letter that corresponds to the best answer.

11. Which of the following statements is *true*?

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

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

For problems 12 - 15, consider the following disturbances to systems at equilibrium and predict the nature of the shift in equilibrium position.

12. The exothermic reaction is heated 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.

13. $N_2(g)$ is added to the system $C_2H_2N_4(g) \rightleftharpoons 2\ N_2(g) + C_2H_2(g)$.

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

14. The volume is decreased on the system $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$.

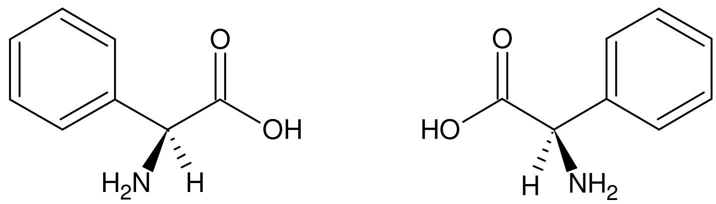
(A) The equilibrium will shift left.
(B) The equilibrium will shift right.
(C) The equilibrium position will not change.

15. $CaO(s)$ 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.

For 16-19, circle whether the pair of molecules shown are not isomers, structural isomers, linkage isomers, geometric isomers, or optical isomers.

16.



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

17.

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

18.

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

19.

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

20. The heaviest known elements are synthesized in particle accelerators by nuclear fusion. In order to synthesize element 114 (mass number 289), a metal target is bombarded with calcium-48 nuclei and three neutrons are produced for every nucleus of element 114. What is the identity of the metal target in this reaction?

(A) $^{238}_{91}Pa$
(B) $^{238}_{92}U$
(C) $^{241}_{91}Pa$
(D) $^{241}_{94}Pu$
(E) $^{244}_{94}Pu$

For problems 21-24, 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 compounds.

Substance	K_a	K_b
HNO_2	7.25×10^{-4}	
C_5H_5N		1.48×10^{-9}

21. KNO_2

(A) produces an acidic solution
(B) produces a basic solution
(C) produces a neutral solution

22. C_5H_5NHCl

(A) produces an acidic solution
(B) produces a basic solution
(C) produces a neutral solution

23. KNO_3

(A) produces an acidic solution
(B) produces a basic solution
(C) produces a neutral solution

24. $C_5H_5NHNO_2$

(A) produces an acidic solution
(B) produces a basic solution
(C) produces a neutral solution

25. Which of the following alkane names is unambiguous and systematically correct?

(A) 3-methylbutane
(B) 2,2,2-trimethylbutane
(C) 2-methylbutane
(D) 1-methylbutane
(E) methylpentane

26. Technetium-99 is an unstable nuclide which is consumed by the following process:

$$^{99}_{43}\mathrm{Tc} \longrightarrow {}^{0}_{-1}\mathrm{e} + {}^{99}_{44}\mathrm{Ru}$$

What is this process an example of?

(A) fission
(B) fusion
(C) positron emission
(D) alpha decay
(E) beta decay

27. Which of the following are conjugate acid/base pairs?

I. HNO_3 and NO_3^-
II. H^+ and OH^-
III. $H_2PO_4^-$ and HPO_4^{2-}
IV. C_5H_5N and $C_5H_5NH^+$

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

28. How many protons, neutrons, and electrons are in radon-222?

(A) 88 protons, 88 neutrons, 134 electrons
(B) 88 protons, 222 neturons, 88 electrons
(C) 88 protons, 134 neutrons, 88 electrons
(D) 134 protons, 88 neutrons, 134 electrons
(E) 134 protons, 222 neutrons, 88 electrons

29. Given that K >> 1 for a chemical reaction, which of the following are *true*?

I. The equilibrium would be achieved rapidly.
II. The equilibrium would be achieved slowly.
III. Product concentrations will be greater than reactant concentrations at equilibrium.
IV. Reactant concentrations will be greater than product concentrations at equilibrium.
V. The concentrations of reactants and products should be about equal.

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

30. When a galvanic cell is constructed using iron and aluminum, the standard cell potential will be:

(A) -1.66 V
(B) -1.62 V
(C) 1.30 V
(D) 1.62 V
(E) 1.70 V

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

$PV = nRT$

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

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

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

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

$ax^2 + bx + c = 0$

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

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

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

$K_w = 1.00x10^{-14} = [H^+][OH^-]$

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

$pH + pOH = 14.00$

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

$K_a \cdot K_b = K_w$

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

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

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

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

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

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

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

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

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

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

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

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