SCH 4U1 – Final Exam Overview

Date:_____________________

Unit 1
- Quantum theory – 4 quantum numbers, restriction on values
- Pauli exclusion principle
- Aufbau diagram – energy level diagrams
- Hund's rule
- electron configuration
- Lewis dot diagrams
- hybrid orbitals
- VSEPR theory – predicting shape around central atom
- intermolecular forces resulting from polarity of molecule (determined by shape)

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Page 282 #3,4,8,9,10,14,15,17,20

Unit 2
- hydrocarbon nomenclature (alkanes, enes, ynes and cyclic hydrocarbons)
- types of organic reactions – substitution, addition (hydration, hydrohalogenation, halogenation, hydrogenation), Markovnikov's rule
- families of organic molecules (functional groups), preparation
- alcohol, ether, ketone, aldehyde, carboxylic acid, ester amine, amide
- two types of polymerization, addition and condensation

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Unit 3
- heat vs temperature
- calorimetry $q = mc\Delta t$
- $\Delta H_{reaction} = -q_{surroundings}$
- endothermic vs exothermic
- representing enthalpy changes (4 methods)
- Hess's law
- heats of formation
- determining rates of reaction experimentally

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Page 408 #2,10,11

Unit 4
- equilibrium equations
- le Chatelier's principle
- equilibrium law equations, significance of K
- ICE tables
- Q as it relates to K
- assumptions (rule of 100 and % difference)
- solubility product K_{sp}
- acid/base equilibrium (pH, pOH, k_w, k_a, k_b, strong vs weak)
- acidic/basic properties of salt solutions (conjugate acid/base)
- titrations

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Unit 5
- oxidation and reduction / oxidizing agent and reducing agents
- electron transfer theory
- oxidation numbers (assigning)

- balancing redox by half reaction
- relative redox table
- spontaneous redox reactions and net equations

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Chapter 3 REVIEW

Understanding Concepts

1. Scientific theories are usually developed to explain the results of experiments. Describe the evidence that the following scientists used to develop their atomic models. Include the main interpretation of the evidence.
   (a) Rutherford
   (b) Bohr (3.4)
2. When a theory is not able to explain reliable observations, it is often revised or replaced. The Rutherford and Bohr atomic models represent stages in the development of atomic theory. Describe the problems with each of these models. (3.4)
3. State a similarity and a difference between the terms "orbit" and "orbital." Which atomic models that you have studied would use each of these terms? (3.5)
4. What was the main kind of experimental work used to develop the concepts of quantum mechanics? (3.5)
5. The quantum mechanical model of the atom involves several theoretical concepts. Describe each of the following concepts:
   (a) quantum
   (b) orbital
   (c) electron probability density
   (d) photon (3.7)
6. The Pauli exclusion principle states that no two electrons in an atom can have the same set of four quantum numbers. Draw an energy-level diagram for the ground-state oxygen atom and label the features that provide the following information.
   (a) the main/principal energy level
   (b) the energy sublevel (subshell)
   (c) the orientation of an orbital
   (d) the spin of the electron (3.6)
7. What evidence indicates that electrons have two directions of spin? (3.6)
8. Draw an outline of the periodic table and label the sublevels (subshells) being filled in each part of the table. (3.6)
9. According to quantum mechanics, how does the position of an element on the periodic table relate to its properties? (3.6)
10. Complete energy-level diagrams for potassium ions and sulfide ions. Which noble gas atom has the same diagrams as these ions? (3.6)
11. (a) What are some similarities in the chemical properties of alkali metals?
    (b) How is this explained theoretically, using concepts in this chapter? (3.6)
12. Write a complete ground-state electron configuration for each of the following atoms or ions:
    (a) Mg
    (b) S^{2-}
    (c) K^{+}
    (d) Rb
    (e) Au (3.6)
13. Write the shorthand electron configuration for each of the following atoms or ions:
    (a) yttrium
    (b) antimony
    (c) barium ion (3.6)
14. Paramagnetic substances are attracted by a magnet. Indicate which of the following elements are paramagnetic. Justify your answer.
    (a) aluminum
    (b) beryllium
    (c) titanium
    (d) mercury (3.6)
15. Identify the following atoms or ions from their electron configurations:
    (a) W: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^{10}\,4p^3$
    (b) X^+: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^{10}\,4p^6$
    (c) Y^-: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^{10}\,4p^6\,5s^2\,4d^{10}\,5p^6$
    (d) Z: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^{10}\,4p^6\,5s^2\,4d^{10}\,5p^6\,6s^2\,4f^{11}$ (3.6)
16. Calculate the maximum number of electrons with the following principal quantum numbers, n:
    (a) 1
    (b) 2
    (c) 3
    (d) 4 (3.6)
17. Sketch the shape of a $2p_x$ orbital. How is this orbital the same as and different from the $2p_y$ and $2p_z$? (3.7)
18. The quantum mechanical model of the atom has been called "the greatest collective work of science in the 20th century," because so many individuals contributed to its development. Briefly describe the contributions of each of the following scientists:
    (a) Max Planck
    (b) Louis de Broglie
    (c) Albert Einstein
    (d) Werner Heisenberg
    (e) Erwin Schrödinger (3.7)
19. A scientific concept can be tested by its ability to describe and explain evidence gathered by scientists.

Chapter 4 REVIEW

1. Draw Lewis symbols for atoms of the following elements and predict their bonding capacity:
   (a) calcium (d) silicon
   (b) chlorine (e) sulfur
   (c) phosphorus (4.1)
2. Describe the requirements for valence electrons and orbitals in order for a covalent bond to form between two approaching atoms. (4.2)
3. According to atomic theory, how many lone electron pairs are on the central atom in molecules of the following substances?
   (a) $HF_{(g)}$ (d) $CCl_{4(l)}$
   (b) $NH_{3(g)}$ (e) $PCl_{3(l)}$
   (c) $H_2O_{(l)}$ (4.2)
4. Draw Lewis symbols for atoms with the following electron configurations:
   (a) $1s^2\,2s^2\,2p^5$ (d) $[Ar]\,4s^2\,3d^{10}\,4p^4$
   (b) $1s^2\,2s^2\,2p^6\,3s^2\,3p^3$ (e) $[Kr]\,5s^2$
   (c) $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^1$ (4.2)
5. The American chemist G. N. Lewis suggested that atoms react in order to achieve a more stable electron configuration. Describe the electron configuration that gives an atom maximum stability. (4.2)
6. Compounds of metals and carbon are used in engineering because of their extreme hardness and strength. The carbon in these metallic carbides behaves as the C^{4-} ion.
   (a) Write the electron configuration for a carbide ion.
   (b) Calculate the number of protons, electrons, and neutrons in a carbide ion, $^{12}_{6}C^{4-}$, and state their relative position in the ion. (4.2)
7. The theory of hybridization of atomic orbitals was developed to explain molecular geometry. Sketch and name the shape of each of the following hybrid orbitals of a carbon atom in a compound:
   (a) *sp* (b) sp^2 (c) sp^3 (4.2)
8. Identify the types of hybrid orbitals found in molecules of the following substances:
   (a) $CCl_{4(l)}$ (c) $BeI_{2(s)}$
   (b) $BH_{3(g)}$ (d) $SiH_{4(g)}$ (4.2)
9. What is the difference between a sigma bond and a pi bond? (4.2)
10. Indicate the number of sigma and the number of pi bonds in each of the following molecules:
    (a) $H_2O_{(l)}$ (c) $C_2H_{4(g)}$
    (b) $C_2H_{2(g)}$ (d) $C_2H_{6(g)}$ (4.2)
11. Describe any changes in the hybridization of the nitrogen and boron atoms in the following reaction.
    $BF_{3(g)} + NH_{3(g)} \rightarrow F_3B - NH_{3(s)}$ (4.2)
12. The VSEPR model includes several concepts related to atomic theory. Explain the following concepts:
    (a) valence shell (c) lone pair
    (b) bonding pair (d) electron pair repulsion (4.3)
13. Outline the steps involved in predicting the shape of a molecule using the VSEPR model. (4.3)
14. Using VSEPR theory, predict the shape around each central atom in a molecule of each of the following substances:
    (a) $HI_{(g)}$ (d) $CH_{4(g)}$ (g) $NH^{+}_{4(aq)}$
    (b) $BF_{3(g)}$ (e) $HCN_{(g)}$ (h) $H_2O_{2(l)}$
    (c) $SiCl_{4(l)}$ (f) $OCl_{2(g)}$ (4.3)
15. (a) Draw Lewis and shape diagrams for ammonia, methane, and water molecules.
    (b) Use these diagrams to explain why the molecular bond angles decrease in the order, methane > ammonia > water. (4.3)
16. Carbon dioxide is used by green plants in the process of photosynthesis and is also a greenhouse gas produced by fossil fuel combustion.
    (a) Draw a Lewis structure for carbon dioxide.
    (b) Name the shape of a carbon dioxide molecule and give its bond angle.
    (c) Using appropriate bonding theories, predict and explain the polarity of carbon dioxide. (4.4)
17. The polarity of a molecule is determined by bond polarity and molecular shape.
    (a) Compare the polarity of the bonds N−Cl and C−Cl.
    (b) Predict whether the molecules, $NCl_{3(l)}$ and $CCl_{4(l)}$, are polar or nonpolar. Explain your predictions. (4.4)
18. Use appropriate bonding theory to explain the following experimental observations:
    (a) BeH_2 is nonpolar; H_2S is polar.
    (b) BH_3 is planar; NH_3 is pyramidal.
    (c) LiH has a melting point of 688°C; that of HF is −83°C. (4.5)
19. Use the theory of intermolecular bonding to explain the sequence of boiling points in the following alkyl bromides: $CH_3Br_{(g)}$ (4°C), $C_2H_5Br_{(l)}$ (38°C), and $C_3H_7Br_{(l)}$ (71°C). (4.5)
20. Name the intermolecular forces present in the following compounds and account for the difference in

their boiling points: $CH_{4(g)}$ (–164°C), $NH_{3(g)}$ (–33°C), and $BF_{3(g)}$ (–100°C). (4.5)

21. Ionic compounds and metals have different physical properties because of the different forces involved. For example, while sodium chloride and nickel have nearly identical molar masses, their melting points, conductivity, and solubility in water are quite different.
    (a) Explain the large difference in melting point between sodium chloride (801°C) and nickel metal (1453°C).
    (b) Predict the electrical conductivity of each of these substances in the solid state, and provide a theoretical explanation for your prediction.
    (c) Predict the solubility in water of each substance, and provide a theoretical explanation for your prediction. (4.6)
22. Name the forces acting between particles in each of the following substances:
    (a) hexane, $C_6H_{14(l)}$
    (b) 1-butanol, $C_4H_9OH_{(l)}$
    (c) ethylamine, $C_2H_5NH_{2(l)}$
    (d) chloroethane, $C_2H_5Cl_{(l)}$
    (e) calcium carbonate, $CaCO_{3(s)}$
    (f) diamond, $C_{n(s)}$ (4.6)

Applying Inquiry Skills

23. An investigation is to be done to see how well intermolecular force concepts can predict differences in solubility.

Question

What is the order from lowest to highest solubility in water for: pentane, $C_5H_{12(l)}$, 1-butanol, $C_4H_9OH_{(l)}$, diethyl ether, $(C_2H_5)_2O_{(l)}$, butanoic acid, $C_3H_7COOH_{(l)}$?

Prediction

(a) Predict the answer to the question, including your reasoning for each substance.

Experimental Design

(b) Design an experiment to answer the question. Include a brief plan and variables.

Materials

(c) Prepare a list of materials.

Procedure

(d) Write a numbered list of steps, including disposal instructions. (4.5)

24. Hydrocarbons can be oxidized step by step through a series of compounds until they are converted to carbon dioxide and water, e.g., methane (CH_4), methanol (CH_3OH), methanal (CH_2O), methanoic acid (HCOOH), carbon dioxide (CO_2). For each compound in this series draw a structural diagram, and then describe the molecular shape. (4.5)
25. Compare the particles and forces in the following pairs of solids:
    (a) metallic and covalent network
    (b) covalent network and molecular
    (c) molecular and ionic (4.6)

Making Connections

26. Methylamine, CH_3NH_2, is one of the compounds responsible for the unpleasant odour of decomposing fish.
    (a) Draw Lewis and structural diagrams for methylamine.
    (b) Use VSEPR theory to predict the shape around the carbon and nitrogen atoms in methylamine.
    (c) Methylamine and ethane have similar molar masses. Explain why the boiling point of methylamine is –6°C while that of ethane is –89°C.
    (d) Since amines are bases they react readily with acids. Use structural diagrams to rewrite the following equation for the reaction of methylamine with acetic acid:

$$CH_3NH_{2(aq)} + CH_3COOH_{(aq)} \rightarrow CH_3NH_{3(aq)}^{+} + CH_3COO_{(aq)}^{-}$$

    (e) Explain how vinegar and lemon juice can be used to reduce the odour of fish. (4.3)
27. What material is used in the outer skin of a stealth bomber (**Figure 1**)? Describe how the structure and properties of this material relate to its function. (4.6)

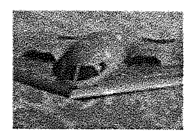

Figure 1

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Extension

28. Chlorine is a very reactive element that forms stable compounds with most other elements. For each of the following chlorine compounds, draw Lewis and structural diagrams, and then predict the polarity of the molecules:
    (a) NCl_3 (c) PCl_5
    (b) $SiCl_4$ (d) SCl_6

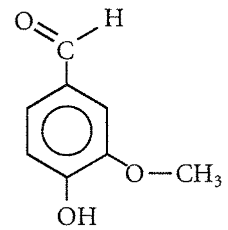
Understanding Concepts

1. Write balanced chemical equations, with structural diagrams, to show each of the following reactions. Explain in general terms any differences in the three reactions.
   (a) One mole of Cl_2 reacts with one mole of 2-hexene.
   (b) One mole of Cl_2 reacts with one mole of cyclohexene.
   (c) One mole of Cl_2 reacts with one mole of benzene. (1.4)
2. The following compounds have comparable molar mass. Arrange the compounds in order of increasing boiling points and give reasons for your answer.

CH_3COOH A	CH_3CH_2CHO B
$CH_3CH_2CH_2CH_3$ C	$CH_3CH_2CH_2OH$ D

(1.6)

3. Write the structural formula for each of the following compounds:
   (a) A secondary alcohol with the formula $C_4H_{10}O$
   (b) A tertiary alcohol with the formula $C_4H_{10}O$
   (c) An ether with the formula $C_4H_{10}O$
   (d) A ketone with the formula C_4H_8O
   (e) An aromatic compound with the formula C_7H_8
   (f) An alkene with the formula C_6H_{10}
   (g) An aldehyde with the formula C_4H_8O
   (h) A carboxylic acid with the formula $C_2H_4O_2$
   (i) An ester with the formula $C_2H_4O_2$ (1.7)
4. Analysis of an unknown organic compound gives the empirical formula $C_5H_{12}O$. It is slightly soluble in water. When this compound is oxidized in a controlled way with $KMnO_4$, it is converted into a compound of empirical formula $C_5H_{10}O$, which has the properties of a ketone. Draw diagrams of the possible structure(s) of the unknown compound. (1.7)
5. Name the family to which each of the following compounds belongs and write the IUPAC name for each:
   (a) $CH_2{=}CHCH_2CH_3$
   (b) $CH_3{-}O{-}CH_2CH_3$
   (c) $CH_3CH_2CHCH_2OH$ with CH3 on the third carbon
   (d) $CH_3C{\equiv}CH$
   (e) $CH_3CH_2CH_2COOCH_3$
   (f) CH_3CH_2CH with =O on the terminal carbon
   (g) $CH_3CCH_2CH_3$ with =O on the second carbon
   (h) $CH_3CH_2CH_2CH_2NH_2$
   (i) $CH_2{=}CHCHCHCH_2CH_3$ with OH OH on the third and fourth carbons
   (j) $CH_3CH_2CH_2CONHCH_2CH_3$ with =O on the C of CONH (1.8)
6. Many organic compounds have more than one functional group in a molecule. Copy the following structural diagrams. Circle and label the functional groups: hydroxyl, carboxyl, carbonyl, ester, amine, and amide. Suggest either a source or a use for each of these substances.

(a)


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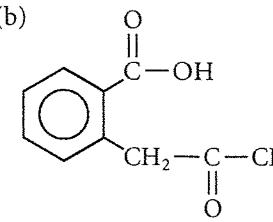

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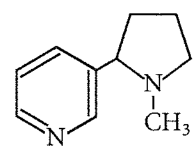

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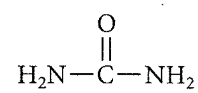

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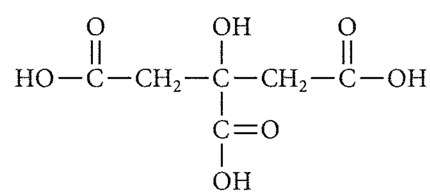

(1.8)

7. Name and classify the chemicals and write a complete structural diagram equation for each of the following reactions. Where possible, classify the reactions.
   (a) $C_2H_6 + Br_2 \rightarrow C_2H_5Br + HBr$
   (b) $C_3H_6 + Cl_2 \rightarrow C_3H_6Cl_2$
   (c) $C_6H_6 + I_2 \rightarrow C_6H_5I + HI$
   (d) $CH_3CH_2CH_2CH_2Cl + OH^- \rightarrow CH_3CH_2CHCH_2 + H_2O + Cl^-$
   (e) $C_3H_7COOH + CH_3OH \rightarrow C_3H_7COOCH_3 + HOH$
   (f) $C_2H_5OH \rightarrow C_2H_4 + H_2O$
   (g) $C_6H_5CH_3 + O_2 \rightarrow CO_2 + H_2O$
   (h) $C_2H_5OH \rightarrow CH_3CHO \rightarrow CH_3COOH$
   (i) $CH_3CHOHCH_3 \rightarrow CH_3COCH_3$
   (j) $NH_3 + C_4H_9COOH \rightarrow C_4H_9CONH_2 + H_2O$
   (k) $NH_3 + CH_4 \rightarrow CH_3NH_2 + H_2$ (1.8)

8. Write a series of equations to illustrate each of the following reactions:
   (a) a substitution reaction of propane
   (b) a halogenation reaction of benzene
   (c) the complete combustion of ethanol
   (d) an elimination reaction of 2-butanol
   (e) the controlled oxidation of butanal
   (f) the preparation of 2-pentanone from an alcohol
   (g) the preparation of hexyl ethanoate from an acid and an alcohol
   (h) the hydrolysis of methyl pentanoate
   (i) the controlled oxidation of 1-propanol
   (j) an addition reaction of an alkene to produce an alcohol
   (k) a condensation reaction of an amine (1.8)
9. Write equations to show the synthesis pathway for ethyl 3-hydroxybutanoate, the flavouring of marshmallows. An alkene and an alcohol of your choice are the starting materials. (1.9)
10. Write balanced chemical equations to represent the synthesis of:
   (a) propanone from a hydrocarbon
   (b) sodium ethanoate from an ester
   (c) propanal from an alcohol
   (d) propanoic acid from 1-propanol
   (e) 1,2-dichloroethane from ethene
   (f) *N*,*N*-dimethylethanamide from an alkane, an alkene, a halogen, and ammonia (1.9)

Applying Inquiry Skills

11. In an experimental synthesis of 1,1-dichloroethane from ethene and chlorine, the following evidence was obtained:

    mass of ethene = 2.00 kg

    mass of 1,1-dichloroethane = 6.14 kg
   (a) Write an equation for the synthesis reaction.
   (b) Calculate the percent yield of 1,1-dichloroethane.
   (c) Suggest some reasons why the actual yield may be different from the theoretical yield. (1.4)
12. Design a procedure to separate a mixture of alcohols containing methanol, ethanol, and 1-pentanol. Explain, with reference to intermolecular forces, why this separation method is effective in this situation. (1.5)
13. Describe a procedure to synthesize the ester ethyl ethanoate, starting from ethene. Include in your answer details of the conditions and safety precautions required for the procedure. (1.7)
14. When esters are prepared in the reaction of an alcohol with a carboxylic acid, the product formed can often be separated from the reactants by cooling the reaction mixture. Is the solid (formed when the reaction mixture is cooled) the alcohol, the acid, or the ester? Explain your answer with reference to the molecular structure of each reactant and product. (1.7)

Making Connections

15. Use print or electronic resources to obtain the molecular structure of glucose, glycerol, and ethylene glycol. All three compounds have a sweet taste.
   (a) Predict the relative melting points and boiling points of rubbing alcohol, ethylene glycol, glycerol, and glucose. Give reasons for your answer.
   (b) Predict the solubility of each of these compounds in water, and in gasoline. Give reasons for your answer.
   (c) Ethylene glycol is toxic and is used as an antifreeze in automobile radiators. Suggest a reason why car antifreeze must be stored safely and spills must be cleaned up.
   (d) Do the structures of these three compounds support the hypothesis that taste receptors respond to functional groups in the compounds tasted? Explain. (1.5)

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16. The distinction between "natural" and "synthetic" products is usually based on the source of the product, whether it is made by living organisms or by a laboratory procedure. Sometimes, the product is in fact the same, but the distinction is made in the way the product is processed. For example, when bananas are dissolved in a solvent and the flavouring extracted, the pentyl ethanoate obtained is labelled "natural flavour." When pentyl ethanoate is synthesized by esterification of ethanoic acid and pentanol, it is labelled "artificial flavour."
   (a) Write an equation for the synthesis of pentyl ethanoate.
   (b) In your opinion, what criteria should be used to distinguish a "natural" product from a "synthetic" product?
   (c) Research the differences in the source and processing methods of vanilla flavouring. Write a report on your findings. (1.9)

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Understanding Concepts

1. Make a chart to summarize the energy changes involved in physical, chemical, and nuclear changes. For each type of change
   (a) describe the change in matter;
   (b) give a range of energies in kJ/mol; and
   (c) give two examples. (5.1)
2. Bricks in a fireplace will absorb heat and release it long after the fire has gone out. A student conducted an experiment to determine the specific heat capacity of a brick. Based on the evidence obtained in this experiment, 16 kJ of energy was transferred to a 938-g brick as the temperature of the brick changed from 19.5°C to 35.0°C. Calculate the specific heat capacity of the brick. (5.1)
3. What basic assumptions are made in calorimetry experiments that involve reacting solutions? (5.2)
4. A 2.0-kg copper kettle (specific heat capacity 0.385 J/g•°C) contains 0.500 kg of water at 20.0°C. How much heat is needed to raise the temperature of the kettle and its contents to 80.0°C? (5.2)
5. Propane gas is used to heat a tank of water. If the tank contains 200.0 L of water, what mass of propane will be required to raise its temperature from 20.0°C to 65.0°C? (ΔH_{comb} for propane = –2220 kJ/mol) (5.2)
6. Draw a labelled potential energy diagram to represent the exothermic combustion of nonane (C_9H_{20}) in oxygen. (5.3)
7. (a) Describe four ways in which enthalpy changes for a reaction may be represented.
   (b) Use the four methods to represent the dissolving of ammonium chloride ($\Delta H_{sol} = +14$ kJ/mol). (5.3)
8. If one mole of water absorbs 44 kJ of heat as it changes state from liquid to gas, write thermochemical equations, with appropriate energy terms, to represent
   (a) the evaporation of one mole of water;
   (b) the condensation of one mole of water vapour; and
   (c) the evaporation of two moles of water. (5.3)
9. (a) Write the equation for the formation of liquid acetone (C_3H_6O).
   (b) Write thermochemical equations for the combustion of one mole each of hydrogen, carbon, and acetone, given that their molar enthalpies of combustion are −285.8 kJ/mol, −393.5 kJ/mol, and −1784 kJ/mol, respectively.
   (c) Use Hess's law and the three combustion reactions to calculate the enthalpy of formation of acetone. (5.4)
10. When glucose is allowed to ferment, ethanol and carbon dioxide are produced. Given that the enthalpies of combustion of glucose and ethanol are −2813 kJ/mol and −1369 kJ/mol respectively, use Hess's law to calculate the enthalpy change when 0.500 kg of glucose is allowed to ferment. (5.4)
11. The molar enthalpy of combustion of natural gas is −802 kJ/mol. Assuming 100% efficiency and assuming that natural gas consists only of methane, what is the minimum mass of natural gas that must be burned in a laboratory burner at SATP to heat 3.77 L of water from 16.8°C to 98.6°C? (5.4)
12. Pyruvic acid is a molecule involved as an intermediate in metabolic reactions such as cellular respiration. Pyruvic acid ($CH_3COCOOH$) is converted into acetic acid and carbon monoxide in the reaction

    $CH_3COCOOH \rightarrow CH_3COOH + CO$

    If the molar enthalpies of combustion of these substances are, respectively, −1275 kJ/mol, −875.3 kJ/mol, and −282.7 kJ/mol, use Hess's law to calculate the enthalpy change for the given reaction. (5.4)
13. Ammonia forms the basis of a large fertilizer industry. Laboratory research has shown that nitrogen from the air reacts with water, using sunlight and a catalyst to produce ammonia and oxygen. This research, if technologically feasible on a large scale, may lower the cost of producing ammonia fertilizer.
    (a) Determine the enthalpy change of the reaction, using a chemical equation balanced with whole-number coefficients.
    (b) Calculate the quantity of solar energy needed to produce 1.00 kg of ammonia.
    (c) If 3.60 MJ of solar energy is available per square metre each day, what area of solar collectors would provide the energy to produce 1.00 kg of ammonia in one day?
    (d) What assumption is implied in the previous calculation? (5.4)
14. When sodium bicarbonate ($NaHCO_3$) is heated, it decomposes into sodium carbonate (Na_2CO_3), water vapour, and carbon dioxide. If the standard enthalpies of formation of sodium bicarbonate and sodium carbonate are −947.7 kJ/mol and −1131 kJ/mol respectively, calculate the enthalpy change for the reaction. (5.5)

15. When benzoic acid is burned, the enthalpy of combustion is −3223.6 kJ/mol. Use this information and tabulated values of the standard enthalpies of formation of liquid water and carbon dioxide to calculate the standard enthalpy of formation of benzoic acid. (5.5)

Applying Inquiry Skills

16. A series of calorimetric experiments is performed to test Hess's law. Enthalpy changes for two known reactions are determined experimentally:

(1) $CaCO_{3(s)} + 2\,HCl_{(aq)} \rightarrow CO_{2(g)} + H_2O_{(l)} + CaCl_{2(aq)}$

$\Delta H_1 = ?$ kJ

(2) $CaO_{(s)} + 2\,HCl_{(aq)} \rightarrow H_2O_{(l)} + CaCl_{2(aq)}$

$\Delta H_2 = ?$ kJ

The target equation is

$CaCO_{3(s)} \rightarrow CO_{2(g)} + CaO_{(s)} \quad \Delta H = ?$ kJ

Experimental Design

Two calorimetry experiments are performed, with the choice of chemical systems such that the enthalpy changes of these two known reactions are equal to the enthalpy change of the unknown target equation.

(a) Use Hess's law to show how the two known equations may be added together to yield the target equation.

Procedure

(b) Describe the series of procedural steps that you would follow to produce the following observations.

Evidence

Table 1 Observations for Calorimetry Investigation

Observation	Experiment 1	Experiment 2
mass of reactant 1	4.2 g $CaCO_{3(s)}$	4.7 g CaO
mass of cup	3.0 g	3.1 g
mass of cup and acid	173.2 g	158.6 g
initial temperature of acid	29.0°C	29.0°C
final temperature of mixture	31.0°C	36.0°C

Analysis

(c) Use the evidence to calculate the enthalpy change in each system. (Assume that the specific heat capacity of the acid solution is 4.18 J/g•°C).

(d) Calculate the enthalpy change for the target equation.

(e) Explain the effect that you would expect on the calculated ΔH for reaction (1) if:

(i) some of the calcium carbonate remained on the weighing paper as it was added to the acid;

(ii) some heat was lost to the air. (5.4)

17. (a) A pure liquid is suspected to be ethanol. Using the energy concepts from this chapter, list as many experimental designs as possible to confirm or refute the suspected identity of the liquid.

(b) Describe some other experimental designs that could be used to determine if the unknown liquid is ethanol. (5.5)

Making Connections

18. (a) Calculate the enthalpy change for
- the condensing of 1.00 mol of steam to water at 100°C.
- the formation of 1.00 mol of water from its elements.
- the formation of 1.00 mol of helium-4 in a hydrogen fusion reaction.

(b) If the preceding enthalpy changes were represented on a graph with a scale of 1 cm per 100 kJ, calculate the distance for each enthalpy change in parts (a), (b), and (c).

(c) Develop an analogy for the relative amounts of energy released in part (a). (5.5)

19. Canadians use more energy per capita than almost any other country in the world.

(a) List some factors that contribute to this level of consumption.

(b) Compare Canada's energy consumption with that of another country. At the same time, compare the factors listed in (a).

(c) Choose one source of energy used in Canada, and research the efficiency and environmental impact of our use of this type of energy.

(d) Write a short opinion piece on whether it is morally appropriate for Canada to have the present level of energy consumption. (5.6)

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Understanding Concepts

1. What quantitative measurement(s) would be appropriate in order to determine a rate of reaction in each of the following reactions:
   (a) a gas is produced;
   (b) molecular substances form soluble ions;
   (c) colourless ions react to form purple ions. (6.1)
2. List four factors that affect the reaction rate of a homogeneous reaction. (6.2)
3. A cube of solid reactant with sides of 1.00 cm^2 is submerged in a liquid and reacts to form a gas product at an initial rate of 20 mL/s. The solid-liquid interface is 6.00 cm^2 of surface area. If you sliced this cube (like a block of cheese) into 10 slices, and then replaced it in the liquid, predict the initial rate of reaction. (6.2)
4. Use the following chemical reaction equation to predict the effect of the listed changes on the rate of the reaction of zinc metal in hydrochloric acid.

   $$2\,HCl_{(aq)} + Zn_{(s)} \rightarrow H_{2(g)} + ZnCl_{2(aq)} + \text{heat energy}$$

   (a) The concentration of hydrochloric acid is increased.
   (b) The reaction mixture is cooled.
   (c) Finely ground zinc is used instead of large chunks of zinc.
   (d) A solution of copper(II) sulfate is used as a catalyst. (6.2)
5. At 25°C a catalyzed solution of formic acid produces 44.2 mL of carbon monoxide gas in 30.0 s.
   (a) Calculate the rate of reaction with respect to $CO_{(g)}$ production.
   (b) What can you state about how long you would expect the production of the same volume to take
   (i) at 30°C?
   (ii) without the catalyst? (6.2)
6. Chlorine dioxide and hydroxide ions react to form chlorate ions, chlorite ions, and water.

   $$2\,ClO_{2(aq)} + 2\,OH^-_{(aq)} \rightarrow ClO^-_{3(aq)} + ClO^-_{2(aq)} + H_2O_{(l)}$$

   The reaction is found to be second order with respect to chlorine dioxide and first order with respect to hydroxide ions.
   (a) Write a rate equation for the reaction.
   (b) What is the overall order of reaction?
   (c) What would you expect the effect on rate to be of doubling the concentration of chlorine dioxide?
   (d) What would you expect the effect on rate to be of doubling the concentration of hydroxide ions? (6.3)
7. Nitric oxide, $NO_{(g)}$, reacts with chlorine gas, $Cl_{2(g)}$, in the reaction

   $$2NO_{(g)} + Cl_{2(g)} \rightarrow 2\,NOCl_{(g)}$$

   Initial rates of reaction are determined for various combinations of initial concentrations of reactants and recorded in **Table 1**.

Table 1 Observations on Rates of NOCl Production

Trial	Initial [NO] (mol/L)	Initial II [Cl_2] (mol/L)	Rate of production of NOCl (mol/(L•s))
1	0.10	0.10	1.8×10^{-2}
2	0.10	0.20	3.6×10^{-2}
3	0.20	0.20	1.43×10^{-1}

   (a) What is the rate law equation for the reaction?
   (b) What is the rate-determining step?
   (c) Calculate a value for the rate constant, including units.
   (d) Calculate the expected rate of reaction if the initial concentrations of NO and Cl_2 gases were 0.30 and 0.40 mol/L, respectively. (6.3)
8. (a) Explain what is meant by the term "half-life."
   (b) If the half-life of a radioisotope is 3.5 a, what percentage of the original isotope remains after 14.0 a? (6.3)
9. Sketch a potential energy diagram for the endothermic formation reaction of nitrogen and oxygen to produce nitrogen dioxide. Using appropriate symbols, label the activation energy and enthalpy change on the diagram. (6.4)
10. Draw a sketch, roughly to scale, of the potential energy diagram for a system in which $E_a = +80$ kJ and $\Delta H = -20$ kJ. Label the axes, reactants, products, the activation energy, the activated complex, and the enthalpy change. (6.4)
11. (a) How many particles are generally involved in an elementary step in a reaction mechanism?
    (b) Using a collision model, explain why it is unlikely that larger numbers of particles will be involved in an elementary step. (6.4)
12. (a) Explain how the following statement is not quite accurate: "A catalyst is a substance that speeds up a chemical reaction without itself reacting."
    (b) Explain the difference between homogeneous and heterogeneous catalysts, and provide an example of each. (6.5)

Understanding Concepts

1. (a) What is chemical equilibrium?
   (b) On what concept does the idea of chemical equilibrium depend? (7.1)
2. What are two ways to describe the relative amounts of reactants and products present in a chemical reaction at equilibrium? (7.1)
3. Describe and explain a situation in which a soft drink is in
   (a) a non-equilibrium state.
   (b) an equilibrium state. (7.1)
4. Write a statement of Le Châtelier's principle. (7.2)
5. Scientists and technologists are particularly interested in the use of hydrogen as a fuel.

   $2\,H_{2(g)} + O_{2(g)} \rightleftharpoons 2\,H_2O_{(g)}$ $\quad K = 1 \times 10^{80}$ at SATP

   What interpretation can be made about the relative proportions of reactants and products in this system at equilibrium? (7.2)
6. What variables are commonly manipulated to shift the position of a system at equilibrium? (7.3)
7. How does a change in volume of a closed system containing gases affect the pressure of the system? (7.3)
8. In many processes in industry, engineers try to maximize the yield of a product. How can the concentrations of reactants or products be manipulated to increase the yield of product? (7.3)
9. For each of the following descriptions, write a chemical equation for the system at equilibrium. Communicate the position of the equilibrium with equilibrium arrows, then write a mathematical expression of the equilibrium law for each chemical system.
   (a) At high temperatures, the formation of water vapour from hydrogen and oxygen is quantitative.
   (b) The reaction of carbon monoxide with water vapour to produce carbon dioxide and hydrogen has a percentage yield of 67% at 500°C.
   (c) A combination of low pressure and high temperature provides a percentage yield of less than 10% for the formation of ammonia in the Haber process. (7.4)
10. In a sealed container, nitrogen dioxide is in equilibrium with dinitrogen tetroxide.

    $2\,NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$ $\quad K = 1.15,\ t = 55°C$

    (a) Write the equilibrium law expression for this chemical system.
    (b) If the equilibrium concentration of nitrogen dioxide is 0.050 mol/L, predict the concentration of dinitrogen tetroxide.
    (c) Write a prediction for the shift in equilibrium that occurs when the concentration of nitrogen dioxide is increased. (7.3)
11. Predict the shift in the following equilibrium system resulting from each of the following changes.

    $4\,HCl_{(g)} + O_{2(g)} \rightleftharpoons 2\,H_2O_{(g)} + 2\,Cl_{2(g)} + 113\ kJ$

    (a) an increase in the temperature of the system
    (b) an increase in the volume of the container
    (c) an increase in the concentration of oxygen
    (d) the addition of a catalyst
    (e) addition of $Ne_{(g)}$ at constant volume (7.3)
12. Chemical engineers use Le Châtelier's principle to predict shifts in chemical systems at equilibrium resulting from changes in the reaction conditions. Predict the changes necessary to maximize the yield of product for each of the following important industrial reactions.
    (a) the production of ethene (ethylene)

    $C_2H_{6(g)} + \text{energy} \rightleftharpoons C_2H_{4(g)} + H_{2(g)}$

    (b) the production of methanol

    $CO_{(g)} + 2\,H_{2(g)} \rightleftharpoons CH_3OH_{(g)} + \text{heat}$ (7.3)
13. For each example, predict whether, and in which direction, the equilibrium is shifted by the change imposed. Explain any shift in terms of changes in forward and reverse reaction rates.
    (a) $Cu^{2+}_{(aq)} + 4\,NH_{3(g)} \rightleftharpoons Cu(NH_3)^{2+}_{4(aq)}$
    $CuSO_{4(s)}$ is added
    (b) $CaCO_{3(s)} + \text{energy} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$
    temperature is decreased
    (c) $Na_2CO_{3(s)} + \text{energy} \rightleftharpoons Na_2O_{(s)} + CO_{2(g)}$
    sodium carbonate is added
    (d) $H_2CO_{3(aq)} + \text{energy} \rightleftharpoons CO_{2(g)} + H_2O_{(l)}$
    volume is decreased
    (e) $KCl_{(s)} \rightleftharpoons K^+_{(aq)} + Cl^-_{(aq)}$ $\quad AgNO_{3(s)}$ is added
    (f) $CO_{2(g)} + NO_{(g)} \rightleftharpoons CO_{(g)} + NO_{2(g)}$
    volume is increased
    (g) $Fe^{3+}_{(aq)} + SCN^-_{(aq)} \rightleftharpoons FeSCN^{2+}_{(aq)}$
    $Fe(NO_3)_{3(s)}$ is added (7.3)

14. In a container at high temperature, ethyne (acetylene) and hydrogen react to produce ethene (ethylene).

$$C_2H_{2(g)} + H_{2(g)} \rightleftharpoons C_2H_{4(g)}$$

The equilibrium constant is 0.072. At a specific time, the substance concentrations are $[C_2H_{2(g)}] = 0.40$ mol/L, $[H_{2(g)}] = 0.020$ mol/L, and $[C_2H_{4(g)}] = 3.2 \times 10^{-4}$ mol/L. Predict the direction of the reaction shift. (7.5)

15. For the reaction

$$H_{2(g)} + Br_{2(g)} \rightleftharpoons 2\,HBr_{(g)} \qquad K = 12.0 \text{ at } t°C$$

calculate the concentrations of all three substances at equilibrium, if the following amounts of reactants are mixed in a 2.00-L reaction container.

(a) 8.00 mol of hydrogen and 8.00 mol of bromine
(b) 12.0 mol of hydrogen and 12.0 mol of bromine
(c) 12.0 mol of hydrogen and 8.00 mol of bromine (7.5)

16. $CO_{(g)} + H_2O_{(g)} \rightleftharpoons CO_{2(g)} + H_{2(g)}$
$K = 4.00$ at 900°C

In a container, carbon monoxide and water vapour are in the process of reacting to produce carbon dioxide and hydrogen. The concentrations are $[CO_{(g)}] = 4.00$ mol/L, $[H_2O_{(g)}] = 2.00$ mol/L, $[CO_{2(g)}] = 4.00$ mol/L, and $[H_{2(g)}] = 2.00$ mol/L. Determine the direction in which the reaction proceeds to establish equilibrium. (7.5)

17. Find K_{sp} for calcium fluoride at 25°C, given that a 1.00-L sample of the saturated solution, evaporated to dryness, produced 26.76 mg of solid CaF_2. (7.6)

18. Find the molar solubility of calcium oxalate at 25°C, where K_{sp} is 2.3×10^{-9}. (7.6)

Applying Inquiry Skills

19. Consider this system at equilibrium.

$$PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)} \qquad K = 0.40 \text{ at } 170°C$$

(a) One mole of phosphorus pentachloride was initially placed into a 1.0-L container. Once equilibrium had been reached, it was found that the equilibrium concentration of PCl_5 was 0.54 mol/L. **Figure 1** describes the change in $[PCl_5]$ over time.

Copy the graph. Sketch lines to indicate the changing concentrations of $[PCl_3]$ and $[Cl_2]$ over the same time period.

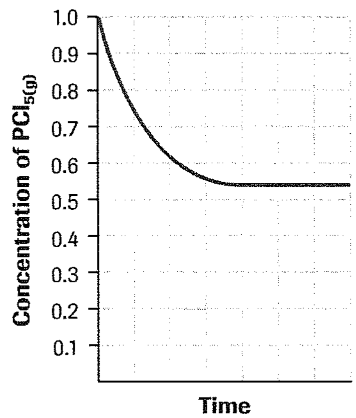

Figure 1

(b) 0.500 mol of PCl_3 and 0.300 mol of Cl_2 were placed into a 1.00-L container. Once equilibrium had been reached it was found that the equilibrium concentration of PCl_3 was 0.360 mol/L. **Figure 2** describes the change in $[PCl_3]$ over time.

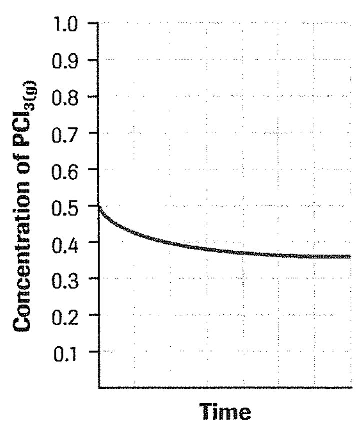

Figure 2

Copy the graph. Sketch how the concentrations of PCl_5 and Cl_2 change over the same time period. (7.1)

20. A student designed an experiment to test the prediction that the addition of a common ion, chloride, can alter the following equilibrium system.

$$Cu^{2+}_{(aq)} + 4\,Cl^-_{(aq)} \rightleftharpoons CuCl_{4(aq)}^{2-}$$
(blue) (green)

Question

What effect does the addition of a common ion (chloride) have on a system at equilibrium?

Experimental Design

Samples (5-mL, 10-mL, and 15-mL) of 1 mol/L hydrochloric acid are added to test tubes containing 10 mL of a copper(II) chloride solution. Similarly,

Understanding Concepts

1. If 8.50 g of sodium hydroxide is dissolved to make 500 mL of cleaning solution, calculate the pOH of the solution. (8.1)
2. (a) Calculate the pH and pOH of a hydrochloric acid solution prepared by dissolving 30.5 kg of hydrogen chloride gas in 806 L of water at SATP.
   (b) What assumptions are made when doing this calculation? (8.1)
3. Sketch a flow chart or concept map that summarizes the conversion of $[H^+_{(aq)}]$ to and from $[OH^-_{(aq)}]$, pH, and concentration of solute. Make your flow chart large enough that you can write the procedure between the quantity symbols in the diagram. (8.1)
4. Unlike the rest of the hydrogen halides, hydrogen fluoride is a weak acid. It is used to etch glass and to produce frosted effects on glass (**Figure 1**). Write the K_a expression for hydrofluoric acid and calculate the hydrogen and fluoride ion concentrations in a 2.0 mol/L solution of this acid at 25°C. (8.2)

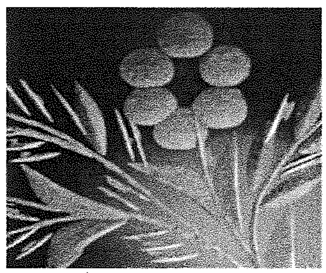

Figure 1

5. At 25°C, the hydroxide ion concentration in normal human blood is 2.5×10^{-7} mol/L. Calculate the hydrogen ion concentration and the pH of blood. (8.2)
6. Acetic acid is the most common weak acid used in industry. Determine the pH and pOH of an acetic acid solution prepared by dissolving 60.0 kg of pure, liquid acetic acid to make 1.25 kL of solution. (8.2)
7. Acetylsalicylic acid (ASA) is a painkiller used in many headache tablets. This drug forms an acidic solution that can sometimes damage the lining of the digestive system. The *Merck Index* lists its K_a at 25°C as 3.27×10^{-4}.
   (a) Calculate the pH of a saturated 0.018 mol/L solution of acetylsalicylic acid, $HC_{10}H_7CO_{4(aq)}$.
   (b) How might the pH change as the temperature changes to 37°C? (8.2)
8. Hydrocyanic acid is a very weak acid.
   (a) Write an equilibrium expression for the ionization of 0.10 mol/L $HCN_{(aq)}$. Include the percent ionization at SATP.
   (b) Calculate $[H^+_{(aq)}]$ and the pH of a 0.10 mol/L solution of $HCN_{(aq)}$ at SATP. (8.2)
9. Sodium ascorbate, the sodium salt of ascorbic acid, is used as an antioxidant in food products. A 0.15 mol/L solution of the ascorbate ion, $HC_6H_6O^-_{6(aq)}$, has a pH of 8.65. Calculate K_b for the ascorbate ion. (8.2)
10. A series of experiments with a non-aqueous solvent determined that the products are highly favoured in each of the following acid–base equilibria.

$$(C_6H_5)_3C^- + C_4H_4NH \rightleftharpoons (C_6H_5)_3CH + C_4H_4N^-$$
$$HC_2H_3O_2 + HS^- \rightleftharpoons H_2S + C_2H_3O_2^-$$
$$O^{2-} + (C_6H_5)_3CH \rightleftharpoons (C_6H_5)_3C^- + OH^-$$
$$C_4H_4N^- + H_2S \rightleftharpoons C_4H_4NH + HS^-$$

   (a) Identify the Brønsted-Lowry acids, bases, and conjugate acid–base pairs in these chemical reactions.
   (b) Arrange the acids in the four chemical reactions in order of decreasing acid strength; that is, prepare a table of acids and bases. (8.2)
11. Sodium methoxide, $NaCH_3O_{(s)}$, is dissolved in water. Will the final solution be acidic, basic, or neutral? Explain your answer, using a net ionic equation. (8.3)
12. Compounds may be classified as ionic or molecular. Each of these classes can be subdivided into neutral substances, acids, and bases. Construct a flow chart that includes two examples for each of the six categories under the headings "Ionic" and "Molecular." (8.3)
13. If the pH of a solution is 6.8, what is the colour of each of the following indicators in this solution?
   (a) methyl red
   (b) chlorophenol red
   (c) bromothymol blue
   (d) phenolphthalein
   (e) methyl orange (8.4)
14. Three separate 25.0-mL samples of a diluted rust-removing solution containing phosphoric acid were each titrated to the second endpoint using 1.50 mol/L sodium hydroxide. The average volume of $NaOH_{(aq)}$ required to reach the equivalence point was 17.9 mL. What is the concentration of phosphoric acid in the rust-removing solution? (8.4)
15. Sketch the pH (titration) curve for 15.0 mL of 0.10 mol/L $HCl_{(aq)}$ being added to 10.0 mL of 0.10 mol/L $NH_{3(aq)}$. Include the following information in your sketch. Show all calculations.
   (a) the equivalence point of the reaction
   (b) the initial pH of the ammonia solution
   (c) the pH after adding 5.0 mL of $HCl_{(aq)}$
   (d) the entities present at the equivalence point
   (e) the pH after adding 10.0 mL of $HCl_{(aq)}$
   (f) the pH after adding 15.0 mL of $HCl_{(aq)}$
   (g) an indicator for an endpoint (8.4)

Understanding Concepts

1. Write theoretical definitions for each of the following words in terms of both electrons and oxidation states:
   (a) oxidation
   (b) reduction
   (c) redox reaction (9.1)
2. Write and label balanced half-reaction equations for each of the following redox reactions:
   (a) $2\ Fe^{3+}_{(aq)} + Ni_{(s)} \rightarrow 2\ Fe^{2+}_{(aq)} + Ni^{2+}_{(aq)}$
   (b) $Br_{2(aq)} + 2\ I^-_{(aq)} \rightarrow 2Br^-_{(aq)} + I_{2(s)}$
   (c) $Pd^{2+}_{(aq)} + Sn^{2+}_{(aq)} \rightarrow Pd_{(s)} + Sn^{4+}_{(aq)}$ (9.1)
3. Assign an oxidation number to
   (a) I in $I_{2(s)}$
   (b) I in $CaI_{2(s)}$
   (c) I in $HIO_{(aq)}$
   (d) H in $NH_{3(g)}$
   (e) H in $AlH_{3(s)}$ (9.1)
4. Assign oxidation numbers to all atoms/ions and indicate which atom/ion is oxidized and which is reduced.
   (a) $2\ Al_{(s)} + Fe_2O_{3(s)} \rightarrow 2\ Fe_{(s)} + Al_2O_{3(s)}$
   (b) $In_{(s)} + 3\ Tl^+_{(aq)} \rightarrow In^{3+}_{(aq)} + 3\ Tl_{(s)}$
   (c) $2\ Cr^{3+}_{(aq)} + Sn^{2+}_{(aq)} \rightarrow 2\ Cr^{2+}_{(aq)} + Sn^{4+}_{(aq)}$
   (d) $Cl_{2(aq)} + 2\ I^-_{(aq)} \rightarrow 2Cl^-_{(aq)} + I_{2(aq)}$
   (e) $UCl_{4(s)} + 2\ Ca_{(s)} \rightarrow 2CaCl_{2(s)} + U_{(s)}$ (9.1)
5. Make a list of everything that must be balanced in a net ionic equation representing a redox reaction. (9.2)
6. The silver(II) ion, used in chemical analysis, reacts spontaneously with water according to the following (unbalanced) equation:

   $$Ag^{2+}_{(aq)} + H_2O_{(l)} \rightarrow Ag^+_{(aq)} + O_{2(g)}$$

   (a) Assign an oxidation number to each atom or ion.
   (b) Balance the equation, assuming an acid solution. (9.2)
7. Use the oxidation number method to balance the reaction equations for the following redox reactions in acid solutions:
   (a) $Cu_{(s)} + HNO_{3(aq)} \rightarrow Cu(NO_3)_{2(aq)} + NO_{(g)} + H_2O_{(l)}$
   (b) $MnO^-_{4(aq)} + H_2C_2O_{4(aq)} \rightarrow Mn^{2+}_{(aq)} + CO_{2(g)} + H_2O_{(l)}$
   (c) $KIO_{3(aq)} + KI_{(aq)} + HCl_{(aq)} \rightarrow KCl_{(aq)} + I_{2(s)} + H_2O_{(l)}$ (9.2)
8. Write equations for the reduction and oxidation half-reactions, and balanced net redox equation.
   (a) $O_{3(g)} + I^-_{(aq)} \rightarrow IO^-_{3(aq)} + O_{2(g)}$ (acidic)
   (b) $Pt_{(s)} + NO^-_{3(aq)} + Cl^-_{(aq)} \rightarrow PtCl^{2-}_{6(aq)} + NO_{2(g)}$ (acidic)
   (c) $CN^-_{(aq)} + ClO^-_{2(aq)} \rightarrow CNO^-_{(aq)} + Cl^-_{(aq)}$ (basic)
   (d) $PH_{3(g)} + CrO^{2-}_{4(aq)} \rightarrow Cr(OH)^-_{4(aq)} + P_{4(s)}$ (basic)
   (e) $MnO^{2-}_{4(aq)} \rightarrow Mn^{2+}_{(aq)} + MnO^-_{4(aq)}$ (acidic) (9.2)
9. While working on the development of a new electrochemical cell, a research chemist places selected Period 4 transition metal strips into aqueous solutions of their ionic compounds. She observes that the following combinations of metal and cation react spontaneously:

   $$V_{(s)} + Mn^{2+}_{(aq)} \rightarrow V^{2+}_{(aq)} + Mn_{(s)}$$
   $$V^{2+}_{(aq)} + Ti_{(s)} \rightarrow V_{(s)} + Ti^{2+}_{(aq)}$$
   $$Co^{2+}_{(aq)} + Mn_{(s)} \rightarrow Co_{(s)} + Mn^{2+}_{(aq)}$$

   (a) Use this information to develop a table of oxidizing and reducing agents for these metals and their ions.
   (b) Identify the strongest oxidizing and the strongest reducing agent in your table. (9.3)
10. For each of the following situations, list and classify the entities present, write the equations for the half-reactions and the overall equation, and then predict whether a spontaneous reaction will be observed.
   (a) Nitric acid is added to aqueous potassium bromide.
   (b) Aqueous potassium permanganate is used to titrate an acidic solution of iron(II) sulfate.
   (c) A strip of copper is placed in a beaker of hydrochloric acid.
   (d) An iron pipe is exposed to the wind and the rain.
   (e) Aqueous cobalt(II) sulfate is mixed with a basic solution of sodium sulfite.
   (f) Aqueous solutions of chromium(II) nitrate and tin(II) nitrate are mixed together. (9.3)
11. Calcium metal spontaneously reacts with water.
   (a) Write the half-reaction and net ionic reaction equation for this reaction.
   (b) Describe diagnostic tests that could be done to test for the predicted products. (9.3)
12. State and describe the three main components of a simple electric cell. (9.4)
13. The mercury cell is a special cell for products such as watches and hearing aids. The equations for the half-reactions are

   $$HgO_{(s)} + H_2O_{(l)} + 2\ e^- \rightarrow Hg_{(l)} + 2\ OH^-_{(aq)}$$
   $$Zn_{(s)} + 2\ OH^-_{(aq)} \rightarrow ZnO_{(s)} + H_2O_{(l)} + 2\ e^-$$