<u>Student Competencies</u>: These will be updated as the semester progresses.

Fundamentals Chapters:

1. Know the SI prefixes ranging from 10^{-12} to 10^{12}; be able to accurately and rapidly convert from units with one prefix to another.

2. Demonstrate proficiency in rapidly converting from one unit to another.

3. Demonstrate the ability to calculate translational kinetic energies.

4. Determine the gravitational potential energy change associated with a change in position.

5. Be able to calculate the potential energy change associated with changes in positions of two electrostatic charges with respect to one another.

6. Demonstrate an understanding of how to use the density equation to rapidly determine volume, mass or density.

7. Demonstrate effective use of the factor-label method to solve a given problem.

8. Demonstrate proficiency in using equations to solve for and to calculate any one of the quantities from all the given others.

9. Understand the first law of thermodynamics (conservation of energy) and effectively apply it to given problems.

Chapter 1 Atoms: The Quantum World

1. Given the wavelength, frequency, or photon energy of electromagnetic radiation in any units; demonstrate proficiency to rapidly calculate energy, frequency or wavelength of the given radiation.

2. Understand the relative energies, frequencies, and wavelengths for different parts of the electromagnetic spectrum. Know the wavelengths, in nm, for the visible, UV-A, UV-B, and UV-C regions. Understand atmospheric transparency for these parts of the electromagnetic spectrum.

3. Understand thermal radiation and how it changes with temperature. Know and apply Wien’s law for star temperatures and wavelengths of maximum intensity. Understand and explain the enhanced greenhouse effect. Apply the phenomenon of thermal radiation to various problems.

4. Use the DeBroglie wave equation and the Heisenberg Uncertainty Principle to calculate wavelengths of particles and uncertainties in velocity or position.

5. Calculate the frequency, wavelength, or energy difference between any two levels of the hydrogen atom. Explain and understand the basis for line spectra.

6. Understand what the photoelectric effect is and solve quantitative problems involving the photoelectric effect.

Chapter 17: Nuclear Chemistry

1. Identify the five main types of radioactive decay and write balanced nuclear equations for given processes.

2. Given a radioactive isotope, predict the expected modes of radioactive decay; fully support your reasoning and write balanced nuclear equations for the processes.

3. Explain the underlying reasons for why certain isotopes are radioactive.

4. Write the set of reactions that occurs in humans exposed to ionizing nuclear radioactivity and clearly explain the mechanism of toxicity.

5. Complete balanced nuclear transmutation equations.

6. Understand the basis for positron emission tomography.

7. Calculate binding energies per nucleon for any given isotope. Understand how the binding energy per nucleon changes for different numbers of nucleons. Be able to clearly explain the scientific basis for nuclear binding energies, nuclear fission, and nuclear fusion.

8. Clearly explain the scientific basis for the generation of energy by nuclear power plants and by the sun. Explain the origin of nuclei in the universe that are now found in the human body.

9. Use first order kinetics to calculate the age of a substance or the amount remaining at any given time. Demonstrate problem solving skills in assessing or in estimating unknown values involving radioactive decay.

Chapter 1 Atoms: The Quantum World

1. Sketch the wavefunctions for the first several energy levels of a particle in a box.

2. Describe the physical significance of a wavefunction and of its curvature.

3. Calculate differences in energy between different energy states for a particle in a box.

4. Write the set of four quantum numbers in the order electrons are added for a given atom or ion. Know what quantum numbers are allowable for each energy level.

5. Write the correct complete or inert gas core electron configuration for any atom or ion.

6. Understand and use Coulomb's Law to clearly and to completely explain the physical basis for periodic trends in atomic/ionic size, ionization energies, electronegativities, or electron affinities.

Chapter 2 Chemical Bonds

1. Outline the energetic basis for covalent bond formation between atoms.

2. For any given main group element, rapidly predict the normal number of bonds atoms form when present in molecules.

3. Know specifically how formal charges and oxidation numbers are each determined.

4. For any given molecule or ion and without any errors, rapidly draw the correct and best Lewis structure to include all formal charges and resonance structures.

Chapter 3 Molecular Structure and Shape

1. For any given molecule or ion with two to six groups of electrons around the central atom; predict electron arrangement, molecular geometry, polarity, bond angles, hybridization, number of pi and sigma bonds, and bond orders.

2. Clearly explain the basis for the formation of single and double bonds.

3. Clearly explain the basis for the valence electron shell pair repulsion theory and apply it to molecular geometry and electron arrangement.

4. Understand the small changes in bond angles that occur when lone pairs of electrons are on the central atom.

Chapter 5 Liquids and Solids

1. For any given substance, draw the Lewis structure, and identify the intermolecular forces of attraction between two molecules; be able to clearly describe and illustrate each type of intermolecular attraction.

2. Demonstrate competence in predicting and in explaining the scientific basis for differences in vapor pressure, boiling/melting point, viscosity, surface tension, and other physical properties for a given set of substances.

3. Know the quantities of energy required to break chemical bonds or to separate molecules; demonstrate an understanding of these relative quantities.

4. Understand how potential energy changes as bonds are stretched or compressed or as molecules are separated or brought together. Be able to effectively diagram these changes.

5. Know and clearly be able to diagram the energetics associated with lattice and hydration energies for ionic solids. Be able to predict and to fully explain relative melting points, lattice energies, ion hydration energies and other properties of ionic compounds.

6. Understand the basis for and be able to identify all three types of network solids. Demonstrate an understanding of molecular solids and the basis for the properties they exhibit.

7. Explain what alloys are and outline their advantages and types.

Chapter 7 Thermodynamics: The First Law

1. Be able to solve problems involving heat, work and changes in internal energy.
2. Be able to effectively and to rapidly calculate changes in enthalpy using calorimetry, Hess' Law, enthalpies of formation, or bond energies.
3. Demonstrate competence in calorimetry calculations involving experimental measurements.
4. Understand the relationship between changes in energy and enthalpy.
5. Write balanced equations for combustion reactions; effectively quantify and discuss the scientific basis for the sources of energy in these reactions.
6. Draw heating curves for given substances; clearly explain the basis for each part of these.

Chapter 8 Thermodynamics: The Second Law

1. Clearly be able to illustrate, discuss, and write an equation for the molecular basis of entropy.

2. Know how to determine the change in entropy for a given reaction or process. Be able to qualitatively predict the sign of the change in entropy for a given reaction; illustrate how entropy of a substance changes as it is heated from 0K.

3. Clearly explain the underlying basis for the Second Law; use it to effectively discuss the large amounts of energy being thrown away by electrical power generation plants.

4. Be able to determine the change in Gibbs Free Energy at any temperature for a given process. Understand and be able to predict the degree of spontaneity from this. Predict the range of temperatures over which a given process or reaction is spontaneous.

Chapter 9 Physical Equilibria

1. Demonstrate a thermodynamic understanding of ionic solid solubility in water.

2. Be able to use and to interpret Henry's Law for gas solubility in liquids. Understand and explain the thermodynamic basis for changes in gas solubility in liquids with temperature.

3. Understand and be able to fully explain the scientific and the thermodynamic basis for liquid-liquid solubility. Describe and portray the structure of surfactant molecules; diagram and clearly describe the self-assembled forms that occur with groups of these molecules.

4. Fully understand and be able to explain the scientific basis for vapor pressures. Be able to use thermodynamics and appropriate equations to calculate enthalpies of vaporizations, vapor pressures, or boiling temperatures. Demonstrate competence in predicting relative vapor pressures and the underlying thermodynamic factors accounting for these differences.

5. Demonstrate competence in writing equilibria constant expressions for given chemical reactions or physical processes. Calculate equilibrium constant values at any temperatures using data from thermodynamic tables.

Chapter 10 Chemical Equilibria

1. Write an expression for the equilibrium constant for a given chemical equation.

2. Predict how chemical equilibria shift in response to various changes in pressure, temperature and concentrations.

3. Given a set of reactant and product concentrations, predict whether the given mixture is at equilibrium and what direction it will shift as it moves to equilibrium.

4. Use thermodynamics to calculate equilibrium constants for chemical reactions.

5. Given a set of initial concentrations, predict the set of reactant and product concentrations that would exist at equilibrium.

6. Explain how equilibrium constants change with temperature; be able to predict constants at a different temperature when given the change in enthalpy and the equilibrium constant at a certain temperature.

Chapters 11-12 Acids and Bases; Aqueous Equilibria

1. Demonstrate an understanding of Bronsted-Lowry and Lewis acids and bases.

2. Be able to write equations and clearly illustrate the basis for molecular changes that occur in reactions between acids and bases.

3. Be able to rapidly identify strong acids and bases.

4. Correctly write chemical equations for the reactions of weak acids and bases with water.

5. Be able to quickly determine pH, $[H_3O^+]$, $\{OH^-]$, and pOH from any given one of these four.

6. Know how to correctly name the major oxyacids and their corresponding ions.

7. Show and use the relationship between K_a and K_b; be able to write the chemical equation that corresponds to the reaction for each.

8. Predict relative strengths of acids and basis; be able to clearly explain the basis for this difference in terms of

fundamental electronic structure and properties.

9. Know what a buffer is and be able to determine the range of pHs over which a given buffer is most effective.

10. Know and use the Henderson-Hasselbalch equation to solve problems involving buffers.

11. Be able to rapidly predict the most concentrated forms of given acids or basis at a certain pH.

Chapter 13 Redox Reactions and Electrochemistry

1. Know specifically what oxidation numbers are and be able to determine all oxidation numbers for a given substance.

2. Understand what an oxidation /reduction reaction is; clearly identify the oxidizing and reducing agents.

3. Balance given redox reactions in acidic media and be able to write balanced half reactions for these.

4. Use a table of reduction potentials to predict spontaneous reactions that occur. Be able to calculate the cell potential, the change in Gibbs Free Energy and the thermodynamic equilibrium constant for this reaction.

5. Be able to diagram the operation of a galvanic cell, to show the reaction that occurs at each electrode and the voltage that should be generated.

6. Use the Nernst equation to relate voltages and concentrations.

7. Explain the basis for the lithium ion battery.

Chapter 14 Chemical Kinetics

1. Clearly explain the molecular basis for how and why reactions occur; outline and fully describe ways to increase the rate of chemical reactions.

2. Be able to calculate the fraction of collisions with sufficient energy to react for reactions having a given activation energy at a given temperature.

3. Clearly draw and fully explain the various parts of an energy-reaction coordinate diagram.

4. Write the rate law for a given reaction.

5. Use experimental data to determine reaction order with respect to each reactant.

6. Be able to conduct concentration-time calculations for first-order and second-order chemical reactions.

7. Know the Arrhenius equation and clearly explain the basis for it.

8. Be able to use rate constants at two or more temperatures to calculate activation energies.

9. Understand how temperature affects reactions with difference activation energies.

10. Understand the basis for catalysis.

11. Be familiar with and explain the basis for Michaelis-Menton enzyme kinetics.