General Chemistry, in broad strokes….

I. Introduction to chemistry, matter, measurements, and naming
    -- The Language of Chemistry

II. Stoichiometry
    -- The Numerical Logic of Chemistry

III. A survey of chemical reactions
    -- Trends in Reactivity

IV. A closer look at atomic and molecular structure
    -- Relating Reactivity to Structure

V. Gases, liquids, solids, and intermolecular forces
    -- Relating Intermolecular Associations to Structure

VI. Chemical Kinetics
    -- Studying *rates* of reactions

VII. Dynamic chemical equilibria
    -- Reactions in balance

VIII. Chemical Thermodynamics
    -- Energy in chemical reactions
    -- Relating equilibrium concepts and thermodynamics

<u>Observing matter</u> (Chapter One)

Matter
- what is it? What is it made of?
- How do we describe the *physical states of matter*?
- Mixtures
	- *homogeneous* (*solutions*) vs. *heterogeneous*
- The building blocks: *elements* vs. *compounds*

Measurements
- conveying information about what is being measured, with
	units
		- *SI units* (be familiar with the units for length, time, mass, and temperature)
		- metric prefixes (mega, kilo, deci, centi, milli, micro, nano, pico)
		- *density* (what it is and how it's measured)
	scientific notation
	indicators of uncertainty
		- *significant figures* (think of the use of sig. fig. as a form of communicating confidence)
		- *accuracy* vs. *precision*
		- preserving the correct number of significant figures in calculations
		- *confidence intervals* (what they are, how to derive them, how to use them)
- converting between different types of measurements -- Dimensional Analysis

<u>Learning to speak the Language</u> (Chapters 2 and 3)
The building blocks of matter -- *atoms*
- atomic structure
    the basic form of an atom: *electrons*, *protons*, and *neutrons* (where is most of the mass of an atom? where is
      most of the volume?)
    atomic number
    mass number
    what changes between atoms of different elements?
    what changes between *isotopic forms* of the same element?
    what changes between atomic and ionic forms of the same element?

Periodic trends
- *metals* vs. *non-metals* vs. metalloids
- common charges on *ions*
- which elements form *diatomic* (elemental) molecules?
- which elements form *ionic* vs. *molecular (covalent) compounds*?

The language of Chemistry
- types of *formulas* (*molecular*, *empirical*, *structural*)
- naming *anions* and *cations* (see Tables 2.5 and 2.6, and the handout)
- naming molecular covalent compounds (be sure to know the prefixes listed in Table 2.7)
- chemical equations (Sections 2.9 and 2.10; this will not be on test #1)
    reactants and products
    physical states
    subscripts vs. coefficients
    balancing them

Stoichiometry (mass-mole-number relationships)
- For elements and compounds
    - what is a *mole* and how is it used to relate macroscopic quantities to microscopic quantities?
    - what is Avogadro's number?
    - determining the *molar mass* of a substance by looking at its chemical formula
    - relating masses of substances to the number of particles they contain
    - interconverting between *mass percent* and molar mass via *empirical formula mass*
- For chemical equations (this will not be on test #1)
    - inferring molar ratios from the coefficients of a balanced chemical equation
    - interconverting between numbers of particles, moles, and masses for all substances in a
       balanced chemical equation ("grams --> moles --> moles --> grams")
    - using stoichiometric relationships to determine the *limiting reagent* in a chemical reaction
    - calculating the *theoretical yield* and *percent yield* of a chemical reaction
    - swimming moles -- using *molarity* to perform stoichiometric analysis of reactions in solution

Aqueous solution chemistry (chapter 4)

Thinking about aqueous solutions at the molecular level
- be able to predict whether a substance will *dissolve* in water (solubility rules)
- be able to predict whether a substance will *dissociate* in water
      - ionic compounds vs. covalent/molecular compounds
          - covalent polyatomic ions do NOT dissociate
      - *strong* vs. *weak acids* and *bases*
- be able to predict whether a mixture will conduct electricity (i.e., is it an *electrolyte*?)
- be able to describe the state of substances in solution by writing *complete ionic* and *net ionic equations*
      - what is a *spectator ion*?

Precipitation (or solubilization) reactions
- typically involve formation of an insoluble solid by double-displacement (*metathesis*)

Acid/base reactions
- in the cases we are concerned with, acid/base reactions involve transfer of *hydrogen ions* (but be sure you understand both the Arrhenius and Bronsted-Lowry definitions of acidity given in your text on pp. 106-107)
- be able to identify acids and bases based on what they do in reactions
- be familiar with the strong acids and strong bases listed in the nomenclature handout
- what is an acid/base *indicator*?
- what is a *neutralization* reaction?
- why do some acid/base reactions liberate gas?
Oxidation-reduction reactions
- be able to assign *oxidation numbers* (see table 4.3)
- be able to identify what is being oxidized or reduced in a reaction on the basis of oxidation numbers of products and reactants
- be able to write and balance *oxidation-reduction half-reactions*

Light and atoms (chapter 7 and 8.1-8.4)

General properties of electromagnetic radiation
- know the relationship between the wavelength, energy, and frequency of different colors of light
    (in other words, know the following equations and when to use them)
    $c = \nu/\lambda$
    $E = h\nu$
- have a casual understanding of the dual nature of light -- both particle-like and wave-like. Understand the meaning of the *de Broglie relationship* (see p. 213; you don't need to know this mathematical relationship, only the concept).
- have a casual understanding of the *Heisenberg uncertainty principle*

Line spectra
- what they are, where the lines come from, what determines their position
- *emission* vs *absorption* of energy in the form of light

The modern model of the atom
- be able to describe differences between the *Bohr model of the atom* and the *quantum mechanical model of the atom*
- *quantum numbers*, *orbital diagrams*, and electron configurations
    - be able to designate the position of electrons in atoms by their quantum numbers, by their positions in an orbital diagram, or by their electron configuration notation (e.g., $1s^2 2s^2 2p^4$)
    - be able to comment on the relative energies of electrons based on their quantum numbers, their positions in an orbital diagram, or their electron configuration notation
    - be able to sketch and recognize the shapes of s, p, and d electron "orbitals" (more properly, electron probability clouds)
    - be able to write a ground-state electron configuration and orbital diagram for any element or ion in the periodic table up through Xenon, embodying the *Pauli Exclusion Principle*, the *Aufbau Principle*, and *Hund's Rule* (for large atoms, use condensed electron configurations with a noble gas core)
    - understand the relationship between electron configuration and magnetic properties of atoms
    - understand how the arrangement of the periodic table reflects shared chemical properties and shared valence electron configurations
    - understand how the arrangement of the periodic table reflects the arrangement of orbitals and sub-orbitals in the quantum-mechanical model of the atom

Using electron configurations to predict properties of atoms and ions (Sections 8.5&8.6)
Be able to understand and predict the periodic trends in:
    - *atomic size*
    - *effective nuclear charge*
    - *ionization energy*
    - *electron affinity*
    - *ionic size*

Molecular Bonding (Chapter 9)

Ionic vs. *polar covalent* vs. "pure" *covalent* bonding
- how are they different?
- be able to predict what kind of bonding will occur between atoms based on *electronegativity* differences
- be able to estimate *relative* electronegativities from position of elements on the periodic table
- understand the general relationship between *bond order* and *bond length* (and strength)

Lewis structures, electronegativity, and bond polarity (sections 9.4-9.8)
- be able to construct *Lewis-dot structures* for atoms and ions
- understand the principle of (and underlying reason for) formation of *octets* of electrons
- be able to indicate bond formation with Lewis structures
- be able to indicate bond *polarity* with Lewis structures
- understand the relationship between electronegativity and oxidation numbers
- understand the meaning of *resonance* structures (this is also an issue with regards to molecular geometry!)
- don't be confused by atoms with '*expanded octets*'

Molecular Geometry and Bonding (Chapter 10)
VSEPR (sections 10.1 and 10.2)
- you should understand the principle of electron-pair repulsion that underlies this model of molecular structure
- you should be able to identify the number of electron domains around an atom on the basis of Lewis structure
- you should be able to determine electron domain geometry from the number of electron domains
- you should be able to determine molecular (i.e., bond) geometry from the electron domain geometry and the number of bonding/non-bonding pairs of electrons

Polarity of bonds and molecules (based on electronegativity differences; sections 9.5 and 10.2)
- you should be able to predict the polarity of almost any bond and any molecule based on molecular geometry and periodic trends in electronegativity

Valence bond theory (sections 10.3 and 10.4)
- bonds occur as the result of overlap between molecular bonding orbitals
- generation of 'hybrid' bonding orbitals to explain molecular shape
- you should be able to identify which hybrid orbitals correspond to which electron-domain geometries
- you should be familiar with the differences between sigma and pi bonding

Correlations between Electronic structure, molecular shape, and orbital hybridization

Number of e⁻ domains	e⁻ domain geometry	*Approximate* angles between e⁻ domains (degrees)	Corresponding hybrid orbitals
2	linear	180	sp (2 orbitals)
3	trigonal planar	120	sp^2 (3 orbitals
4	tetrahedral	110	sp^3 (4 orbitals)
5	trigonal bipyramidal ("trig bipy")	90 or 120, depending on the pair of domains	sp^{3}d (5 orbitals)
6	octahedral	all 90	sp^{3}d^2 (6 orbitals)

You should be comfortable assigning shapes to molecules based on variations to this basic pattern due to mixtures of bonding and non-bonding electron pairs

The behavior of Gases (Chapter 5)
What are gases? (section 5.1)
What is gas pressure? How is it measured?

The kinetic-molecular theory (section 5.6)
- you should have a good mental image of the molecular events that lead to the macroscopic properties of gases as described by the ideal gas law
- you should understand the relationships between particle mass, speed, and temperature
- you should understand how the kinetic molecular theory explains phenomena of *diffusion* and *effusion*

The ideal gas law and its corollaries (sections 5.2 and 5.3)
- what is STP?
- you should KNOW the ideal gas law and what it means
- you should be able to deduce patterns of behavior such as Boyle's and Charles' Laws from the ideal gas law
- you should be able to interconvert between units of pressure, volume, and temperature
- you should be able to quantitatively determine changes in other gas properties that result from changing P, V, n, or T
- you should be able to determine gas properties based on reaction stoichiometry

Applications of the ideal gas law (sections 5.3~5.5)
- relationship of gas properties to density and molar mass
- meaning and applications of partial pressure (and how this relates to *mole fraction*)
- gas volumes and gas-phase reaction stoichiometry

Intermolecular forces and changes in chemical state or phase (Chapter 11)
Intermolecular forces
    - types (ionic, dipole, hydrogen bond, dispersion (London, or induced dipole))
    - predicting types of forces present between molecules based on their structure
    - relative strength of different intermolecular forces
    - how these relate to properties of substances such as state changes, viscosity, surface tension, etc.
    - be able to predict trends in boiling or melting points based on structures of molecules and thus on intermolecular forces
    - be able to explain which forces are most important, given structures and values for boiling or melting points
    - be able to predict general trends in solubility based on structures of molecules and thus on intermolecular forces

Key features of the different states of matter: gases, liquids, and solids
    - what forces operate between molecules in each state?
    - how do the IMF in liquids and solids differ?
    - types of solids (*ionic*, *molecular*, *metallic*, *covalent network*) and the interactions that hold them together

Energy consumption or release that accompanies change in state (breaking intermolecular interactions *consumes* energy; forming them *releases* it)

Does the temperature of a substance change *while* it is changing state?
What does it mean to talk about the *melting point* for a substance? the *boiling point*? What makes the melting or boiling point of one substance higher than another?

Vapor pressure
    - what it is
    - how it is established at the molecular level
    - how it relates to:
        - strength of intermolecular forces (they are inversely proportional; why?)
        - temperature (they are directly proportional; why?)
        - *boiling point* and atmospheric pressure (note that atmospheric pressure does not affect v.p. *per se*)
        - *volatility*
General familiarity with *phase diagrams*, ability to extract data from them or build one from data
    - The concepts of *critical temperature* and *pressure*, and the *triple point*

<u>**Chemical Kinetics -- the study of rates of reaction**</u> (Chapter 13)
What do we mean by *rate* of chemical reactions?
      - the definition of rate -- change in concentration with time
      - the relationship between rates of (dis)appearance for different components from the balanced equation of
      a reaction
      - we determine average rates from data on concentration of reagents at different time points (either
      graphical or tabular)
      - what is the difference between an average rate and an instantaneous rate?

The relationship between the rate of a chemical reaction and the components of that reaction are summarized in an
equation we call a <u>*Rate law*</u>
      - a rate law is unique to the reaction to which it applies
            - you should be able to write a basic rate law for any chemical equation
      - a rate law provides information about <u>*reaction order*</u>
            - order refers to the dependence of rate on concentration of reactants
            - reaction order is **experimentally determined**, in one of two ways
                  - from plots of concentration vs. time, using *integrated rate laws* (see next page)
                  - from a series of experiments that utilize varying starting concentrations of the reactants
            - reaction order tells us
                  - the impact on reaction rate of changing the concentration of one reactant
                  - about the number of molecules that collide in the <u>*rate-determining step*</u> of the reaction
                    mechanism (this is called the <u>*molecularity*</u> of the reaction; "unimolecular",
"bimolecular", etc...)
            - you should know how to determine the magnitude and units of <u>*rate constants*</u>

Reaction rates are governed by the energy of the transition state of the reaction
      - know the relationship between the magnitude of the rate constant for a reaction, k, and the
            <u>*activation energy*</u> for the reaction
            temperature at which the reaction occurs
            <u>*orientation*</u> and frequency of productive <u>*molecular collisions*</u>
      - these effects are encapsulated in the <u>*Arrhenius equation*</u> (which I will provide to you)
      - understand the relationship between reaction rate and the energies of reactants, products, and the
      transition state as presented in <u>*energy profile diagrams*</u> (also called "potential energy diagrams")
            Let me clarify what I mean here: you should be comfortable with energy profile diagrams and be
            able to identify the points on the curve that represent the energies of the reactants, <u>*reaction*</u>
            <u>*intermediates*</u>, transition states, and products.
            - From this sort of diagram you should be able to tell me the energy of activation, and you should
            also be able to comment on the relative energies of the reactants and products -- that is, does the
            reaction liberate energy or consume it?
            - Given energy profiles for two reactions, you should be able to tell which will be the faster
            reaction.
      - understand the principle of <u>*catalysis*</u> (the effects of catalysts and how they work, in general terms)

(items that are <u>*italicized and underlined*</u> are important terms that I expect you to understand)

KINETICS: Integrated rate laws

- to predict the concentrations of reagents at some point in time based on a rate law, or
  to infer the order of a reaction based on the change in concentration of reagents with time
  requires a linear plot of concentration vs. time.

- but with different reaction orders, the concentration dependence changes. What are you to do? Aha!
Calculus to the rescue! Integrating the rate law with respect to time solves the problem, yielding a linear
plot of time versus (some permutation of) concentration.
- this is known as an *integrated rate law*.

Reaction Order	Integrated Rate Law	Linear form	Graphical plot
		$y = mx + b$	y vs x
0	$d[A]/dt = -k$	$[A]_t = -kt + [A]_0$	[A] vs t
1	$d[A]/dt = -k[A]$	$\ln [A]_t = -kt + \ln [A]_0$	ln [A] vs t
2	$d[A]/dt = -k[A]^2$	$1/[A]_t = +kt + 1/[A]_0$	1/[A] vs t

- we use integrated rate laws two ways, as suggested above:
  1) we know the order from previous experiments and we use the integrated rate law to predict
concentration at some point in time
    → plug in values for $[A]_0$ and t, and solve for $[A]_t$
      this can be used to find the *half-life* for a reaction (p. 408-409 in Ebbing)
  2) we know how [A] changes with time, but we don't know the order of the reaction with respect to A,
so we use the integrated rate law expressions to find it
    → plot [A] vs t, (ln[A]) vs t, and (1/[A]) vs t, and see which is most nearly linear
      BEWARE: any dataset will give you a straight line if you only use two points; using more data
      is much more likely to give you the right answer. Moreover, all three of these will probably give
      you a straight line if your time window is too small; generally you should measure [A] over at
      least two half-lives (i.e., wait until $[A]_t < 1/4 [A]_0$)

* Note that "order" in all these cases is just *order with respect to A*, not overall order. To find the overall
order or the overall rate law, one must measure the effect on rate of change in concentration of each
component in turn.

Chemical equilibrium
The concept of dynamic chemical *equilibrium*
The *equilibrium constant*
        - how to write and calculate it
        - what it means in terms of
              - relative concentrations of reactants and products
              - relative rates of formation of reactants and products
              - relative energies of reactants and products
              - relationship to an energy profile diagram

General equilibria (Chapter 14)
        - finding K_{eq} when adding reactions, reversing reactions and multiplying reactions through by a constant
        (- K_c vs K_p)
        - equilibrium constant expressions for reactions involving heterogeneous phases
        - the *reaction quotient*, Q, vs K_{eq}
        - *Le Chatelier's principle*
        - quantitative and qualitative analysis of chemical systems attaining equilibrium
              - know how and when to use an ICE-box, and how and when you can use approximations
                 in solving for equilibrium concentrations

Acid/base equilibria (Chapters 15 and 16)
        - definitions of acids and bases by Arrhenius (you should also recognize the Brønsted/Lowry and Lewis
        theories)
        - *dissociation* of acids and bases (including acidic and basic salts), reactions with water
        - *conjugate acid/base pairs*
        - K_a and K_b (be sure that you can write K_a and K_b equations for **any** conjugate acid/base pair)
        - *autoionization* of water and K_w
        - [H^+], [OH^-], pH, and pOH
        - *weak and strong acids and bases*
        - calculations involving the reactions of acids and bases with water
        - be able to write the multiple successive deprotonation equations that can occur for polyprotic acids

        Other topics in acid/base chemistry, experienced only in lab
        - *neutralization* reactions, both qualitatively and quantitatively
        - *titrations* (as done in lab)

(items that are *italicized and underlined* are important terms that I expect you to understand)

<u>Chemical Thermodynamics -- the study of energy in chemical reactions</u> (Chapters 6 and 18)
The first, second, and third laws of thermodynamics
      - what the definitions are, and what they mean for chemical processes
The language of *<u>thermodynamics</u>* (you should understand these terms and what they imply)
      <u>kinetic, potential, and internal energy</u>
      the *<u>system</u>* versus the *<u>surroundings</u>*
      <u>Entropy</u>
      <u>Enthalpy</u>
      <u>Free Energy</u>
      <u>Heat</u>
      <u>Work</u>
      <u>State function</u>
      <u>Spontaneity</u>
Enthalpy (chapter 6)
      - (calculation from Hess's law and from heats of formation)
      - from *<u>calorimetry</u>*
          in this context, you should understand *<u>Heat Capacity</u>*
      - q vs. H
      - thermochemistry and stoichiometry

Entropy (sections 18.2&18.3)
      - understand the concept, how it relates to spontaneity, to *<u>degrees of freedom</u>*
      - predicting the **relative** magnitudes of entropies of different substances
      - predicting the sign of entropy changes accompanying reactions

Free energy (sections 18.4-18.7)
      - why is it "free"?
      - meaning of the sign of free energy change associated with a chemical process
      - predicting the sign of ΔG given other thermodynamic information
      - the impact of T on ΔG (remember that ΔH and ΔS are relatively *in*sensitive to temperature, unlike ΔG)
      - the relationship between K_{eq}, Q, and $\Delta G°$
       Note that as long as a system is at 298 K, the equations
$$\Delta G = \Delta G° + RT \ln Q \quad \text{and} \quad \Delta G° = -RT \ln K_{eq}$$
      reduce to…
$$\Delta G = RT \ln (Q/K_{eq}).$$
     This clearly relates the sign of ΔG with the relative sizes of Q and K.

      - the impact on ΔG of stressing a system at equilibrium (this is closely tied to the item above)

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