# AP Chemistry

Syllabus

## *Overview*

Our school generally has one or two AP Chemistry groups, with a total of 25-30 students. Each group meets four times, in 55-minute periods, plus one double period per 6-day cycle.

The course is offered as a second-year chemistry course for those students with a minimum grade of a B in the first chemistry course and haven taken Calculus (or are currently enrolled in a Calculus class).

The course is open to any student interested in an advanced, rigorous chemistry class. There is no requirement to take the AP Test at the end of the year, although about 80% of the students decide to take it. The average score is currently 3.6.

<u>The goals of the course are</u>:

- to prepare the students to become critical and independent thinkers, not only in science but in other aspects of their daily life.

- to provide students with the opportunity to critically analyze their own and other students' work, and evaluate their conclusions.

- to help students appreciate the world we live in, how it works and the interconnection among the many physical and chemical systems.

- to provide a strong foundation, both conceptually and in laboratory techniques, for those students interested in pursuing a career in science.

- to provide an opportunity for students to be involved in the completion of a research project from beginning to end.

The course emphasizes on the quantitative aspects of chemistry although other topics are also covered. All students taking this course are already familiar with:

- Measurements, including significant figures
- Atomic theory and Electronic structure
- Periodicity
- Intermolecular (IMF) and Intramolecular bonding. Formulation of ionic and molecular compounds.
- Basic aspects of Molecular Geometry
- Empirical and Molecular Formulas. Formula Stoichiometry.
- Basic Chemical Reactions. Types, balancing and basic product prediction.
- Solution Stoichiometry
- Energy in chemical reactions
- Kinetic Molecular Theory and States of Matter
- Gas Laws

The course has three well-defined sections:

- Review: about 3-week review of the topics covered in the Chemistry-I with special emphasis on solution stoichiometry, empirical formulas, gas laws, formulation and basic chemical reactions.

- Quantitative Chemistry.- This section includes chapters in Thermochemistry, Kinetics, Equilibrium, Acid and Bases, Solubility, Thermodynamics, Electrochemistry.

- Atomic Chemistry.- Including Atomic Theory (electron configurations) and Periodicity, Molecular Bonding and Molecular Geometry, Hybrid Orbitals, Intermolecular Forces and Gases, and Solutions and Colligative properties. Although most of these topics have been covered in Chemistry I, the emphasis is on the correlation between the quantitative chemistry (macroscopic level) and the atomic structure (microscopic level).

<u>Laboratory experiments and other hands-on activities:</u>

During the course students complete about 25 laboratory activities. All the activities are performed in groups of 2 students, and they are required to present their results in individualized lab reports that include the following sections: Chemical Principle and Hypothesis, Methods, Results and Observations, Calculations, and Analysis and Sources of Error. All Lab Reports are kept in a Laboratory Portfolio.

In addition to the laboratory activities, students play an important role in numerous classroom demonstrations and classroom activities, in most cases designed to introduce new concepts in a student-based format and to generate classroom discussion.

After the AP test and for a period of 6 weeks, students, working in pairs, develop a research project from scratch. They are also required to present the project to classmates before (what is the project about, why they want to do it, how will it be done, and expected results) and after (results and observations, analysis of results and conclusions) the completion of the project. This is a student-based project and represents the culmination of all the principles and techniques learned during the year.

<u>Instructional Material:</u>
<u>Textbook:</u>
* *Chemistry: The Central Science* by Brown, Theodore E., H. Eugene LeMay, and Bruce E. Bursten.. Upper Saddle River, NJ: Prentice Hall. Ed. 10e; ISBN: 0-13-146489-2

Other textbooks used for practice problems, tests, etc.
* Kotz, John C., Treichel, Paul M. Jr., Harman, Patrick A, Chemistry and Chemical Reactivity. Grove, CA: Brooks/Cole Thomson Learning. 6th edition
* Zumdahl, Steven, and Susan Zumdahl. *Chemistry*. Boston: Houghton Mifflin. 5th edition
* Chang, Raymond, and Brandon Cruickshank. *Chemistry*. New York: McGraw-Hill. 8th edition

## ***Review of Basic Chemistry (1 week)**** *(Students are required to complete a complete a summer assignment to encourage them to review basic concepts in chemistry)*[*]

(I) **Main Concepts**:

- Measurements and significant figures

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[*] Times are approximate, and vary from year to year based on students needs

- Physical and chemical properties and changes
- Mixtures, compounds and elements. Separation techniques
- Basic atomic structure. Subatomic particles
- Atomic number, average atomic mass
- Ions and isotopes
- Percent composition
- The mole: mass-volume-number of particles conversion
- Empirical, molecular and structural formulas
- Formulation of ionic and molecular compounds
- Basic aqueous stoichiometry: mass-mass, mass-volume problem

(II) **Performance Objectives**:
- Determine the correct number of significant figures
- Write the result of a calculation with the correct number of significant figures
- Distinguish between physical and chemical properties and changes
- Distinguish between mixtures, compounds and elements
- Be familiar with separation techniques, their uses and their limitations
- Identify the parts of the atom
- Locate the basic subatomic particles in the correspondent region of the atom
- Determine the atomic number of an element
- Be familiar with the formation of ions and isotopes
- Write Lewis dot structure of atoms
- Predict the formation of anion and cations based on the position in the PT
- Calculate the average atomic mass of an element based on the percent abundance of isotopes
- Define a mole
- Solve mass-volume-number of particles conversion problems
- Distinguish between empirical, molecular and structural formulas.
- Calculate the percent composition of a substance based on the empirical formula
- Solve problems leading to the determination of the empirical and molecular formulas from experimental data
- Solve basic mass-mass and mass-volume stoichiometry problems
- Write formulas from names, and names from formulas of ionic and molecular compounds

(III) **Laboratory**
- Determination of a Chemical Formula
- Analysis of Silver in an Alloy

## *Descriptive chemistry (2 weeks and continuous practice throughout the year)*

(I) **Main Concepts**:
- Classification of chemical reactions
- Ionization of compounds: electrolytes and non-electrolytes
- Net ionic equations
- Double displacement reactions and Solubility rules
- Neutralization reactions. Strong acids and strong bases
- Redox reaction. Oxidation numbers

(II) **Performance Objectives**:
- List the five basic types of chemical reactions
- Predict the products of reactions based on the type of reaction

- Predict whether a compound will be an electrolyte (strong or weak) or a non-electrolyte
- Predict the product of ionization of electrolytes
- Write net ionic equations
- Identification of spectator ions
- Identify compounds as acid, bases or salts
- Know the solubility rules
- Predict the product of double-displacement reactions and whether a precipitate will form
- Predict the products of neutralization reactions
- Using the activity series for metals and non-metals determine if a single-displacement reaction will occur or not
- Identify single-displacement reactions
- Assign oxidation numbers to atoms in a reaction
- Write the two half-reactions
- Identify the element been reduced and the element being oxidized
- Identify the oxidizing agent and the reducing agent

(III) **Laboratory**

- Qualitative Analysis: Nine-solution Problem (Students are given nine unlabeled solutions. Students are expected to identify each solution (from a list of nine compounds) based on the formation of precipitates with the remaining solutions)

## *Thermochemistry (2 weeks)*

(I) **Main Concepts**:

- Matter and Energy. Types of energy. Units of Energy
- Universe, System and Surroundings: Energy transfers
- First Law of Thermodynamics
- Enthalpy
- Calorimetry: Heat capacity and Specific Heat
- Hess' Law or Law of Constant Heat Summation
- Standard Heat (or Enthalpy) of Formation

(II) **Performance Objectives**:

- List the different types of energy
- Use energy units
- Understand the difference between Universe, System and Surroundings
- Energy transfer in the form of heat and work between the system and the surrounding
- Define State function
- Define enthalpy
- Classify chemical reactions as endothermic or exothermic based on the sign of $\Delta H$
- Sketch enthalpy diagrams for endo- and exothermic reactions
- Solve stoichiometry and energy problems
- Define Heat capacity and Specific Heat
- Solve calorimetry problems: bomb calorimeter, and at constant pressure
- State Hess' Law
- Apply Hess' Law to determine the enthalpy of reactions
- Define and Identify the Standard State for an element or compound
- Understand the concept of Standard Heat (or Enthalpy) of Formation
- Know the value of the Standard Heat of Formation of elements in their most stable

form

- Calculate ΔH of a reaction using tabulated values of standard enthalpies of formation

(III) **Laboratory**

- Heat of Neutralization
- Hess' Law: Determining the Enthalpy Change of a Reaction

## *Kinetics (2 weeks)*

(I) **Main Concepts**:

- Rate of a reaction. Factors that affect it.
- Rate of appearance and rate of disappearance
- Rate Law expressions; Order of the reaction; Rate constant
- Integrated equations
- Collision theory
- Molecular distribution of Kinetic energy
- Effect of temperature on reaction rate
- Activation Energy
- Reaction mechanisms: elementary steps, molecularity, rate limiting step, intermediates
- Catalysts and Activation Energy
- Reversible reactions and Activation Energy

(II) **Performance Objectives**:

- Define rate
- List the main factors that affect the rate of a reaction.
- Determine the rate from the plot of Concentrations vs time: Rate a tangent of the curve
- Determine the rate of appearance from rate of disappearance, and vice versa
- Distinguish between instantaneous and average rates.
- Define Initial Rate
- Write the reaction law expression for a generic reaction
- Define order of the reaction.
- Determine the reaction rate law from experimental data (Concentration – Initial Rate problems)
- Calculation of rate order and rate law using integrated equations (Change of Concentration over Time problems)
- Determine the rate order using a graphical method
- Calculation of Energy of Activation
- Determine the molecularity of elementary steps
- Write the rate law of elementary steps
- Evaluate the validity of proposed reaction mechanisms
- Describe the way catalysts work

(III) **Laboratory**

- Kinetics of Water Flowing (Student-based inquiry activity as an introduction to the topic of kinetics)
- Quantitative Determination of Food Dyes in Powdered Drink Mixes (This is actually a lab to learn the use of the colorimeter and Beer's Law)
- Rate Law Determination of the Crystal Violet Reaction

## *Chemical Equilibrium (3 weeks)*

(I) **Main Concepts**:

- Definition of dynamic equilibrium
- Equilibrium expressions, Keq, Kc, Kp
- Reaction quotient, Q and equilibrium
- Concentrations at equilibrium
- Direction of a chemical reaction to achieve equilibrium
- LeChatelier Principle: equilibrium under stress
- Effect of temperature on the value of Keq
- Equilibrium and catalysis

(II) **Performance Objectives**:

- Name examples of dynamic equilibrium
- Write chemical reaction as equilibrium when appropriate
- Write the equilibrium expression for a chemical reaction
- Calculate Kc or Kp from the all the concentrations at equilibrium are known
- Interconvert Kc and Kp
- Calculation of the reaction quotient, Q
- Identify the equilibrium state of a chemical reaction based on the value of Q as compared to Keq
- Calculate the concentrations at equilibrium when Keq is known – ICE box
- Predict how a chemical reaction at equilibrium responses to stress: LeChatelier Principle
- Predict the response of an equilibrium to a change in temperature
- Describe the effect of temperature on the value of Keq
- Describe the effect of a catalyst on equilibrium

(III) **Laboratory**

- Water transfer: Reaching Equilibrium? (Class wide student-based inquiry activity in which students determine the effect several parameters (initial volume, size or "rate" of transfer) have on reaching equilibrium)
- Spectrophotometric Determination of an Equilibrium Constant (Some years done as a dry lab in which students receive the experimental data)
- Equilibrium and LeChatelier (Students stress a set of reactions at equilibrium and compare the results with their predictions)

## *Acid-Base Reactions and Solution Equilibrium*

**Acid-Base Reactions (2 weeks)**

(I) **Main Concepts**

- Definition of acids and bases based on Arrhenius, Brönsted-Lowry, and Lewis.
- Acid-base conjugate pairs
- Strength of acids and bases
- Equilibrium constant for acids and bases: Ka and Kb
- pH, pOH and Kw
- Acidic, basic and neutral salts.

(II) **Performance Objectives**

- Identify acids and bases using all three definitions
- Write acid-base reactions and identify conjugate pairs

- Write dissociation equation for weak and strong acids and bases
- Define pH and pOH, and perform interconversions
- Define Ka and Kb and write the corresponding expressions
- Calculate pH and pOH from known values of Ka and Kb, and vice versa
- Calculate percent ionization from pH and K values, and vice versa
- Predict the effect of salts on the pH

(III) **Laboratory**

- Using conductivity to find an equivalence point (introductory activity to the concept of neutralization reactions between acids and bases)
- Effect of Salts on the pH of a solution (Student-based inquiry activity to investigate the rules that determine the effect of salt on the pH)

**Buffers and Acid-Base Titrations (2 weeks)**

(I) **Main Concepts**:

- Common ion effect
- Buffers: Definition, pH calculations
- Titrations curves: strong acid/base, weak acid/base
- Application of titrations: determination of concentration, pKa, molar mass

(II) **Performance Objectives**:

- Calculate the concentration of all chemical species upon the mixing of an acid, a base or a salt.
- Calculate the pH upon the mixing of an acid, a base or a salt.
- Identify the basic components of a buffer.
- Describe how a buffer works.
- Describe the physiological buffers found in humans.
- Determine the pH of a buffer before and after the addition of an acid or a base.
- Preparing buffers with a predetermined pH using two methods: (i) from solid salts; (ii) by addition of a strong acid/base
- Identify the different sections of a titration curve.
- Estimate the pH at the equivalence point from the titration curve.
- Predict and calculate the pH at the equivalence time and any other point in a titration
- Calculate the pKa of a weak acid using an acid-base titration
- Calculation of the molar mass of an acid using acid-base titrations

(III) **Laboratory**

- Preparing buffers (In this lab, students roll two dice to determine the pH of the buffer to be prepared from a set of 12 salts. At the end, students must show that they have prepared a buffer solution, they then add enough acid or base to override the buffer effect, resulting in a titration curve.)
- Four titration curves (Student-based inquiry lab to determine the four basic titration curves: strong acid-strong base, weak acid-weak base, weak acid-strong base, weak base-strong acid

**Solubility (1 week)**

(I) **Main Concepts**:

- Solubility and Ksp expression
- Soluble and insoluble salts
- Common ion effect and solubility
- Precipitation of salts

(II) **Performance Objectives**:

- Write Ksp expression
- Distinguish between solubility and Ksp values
- Predict the relative solubility of salts based on their Ksp values
- Calculate the solubility of a salt in the presence or absence of a common ion.
- Predict and determine the effect of pH on the solubility of a salt
- Use the Ksp value to determine whether a precipitate will form upon mixing two solutions

(III) **Laboratory**

- Determination of the solubility product of an ionic compound
- Determination of Calcium Carbonate content in Eggshell (This is putting-all-together lab in which students dissolve an eggshell in HCl and titrate the unreacted HCl, previously titrated with a standardized solution of NaOH)

## *Chemical Thermodynamics (2 weeks)*

(I) **Main Concepts**

- Spontaneous changes; reversible changes.
- Entropy: Definition, as a State Function.
- Second and Third Laws of Thermodynamics.
- Gibbs Free Energy.

(II) **Performance Objectives**

- To define and differentiate spontaneous and reversible changes
- To define Entropy
- To define the Second and Third Laws of Thermodynamics.
- To correlate Entropy and Spontaneity
- To predict the increase or decrease of Entropy in chemical reactions
- To calculate Entropy in chemical reactions using standard molar values.
- To define Gibbs Free Energy in relationship to enthalpy and entropy
- To correlate Free Energy and Spontaneity
- To calculate the value of Free Energy using three different methods
    - From values of enthalpy and entropy
    - Using Hess' Law
    - As a state function
- To calculate Free Energy under non-standard conditions
- To correlate Free Energy and the Equilibrium Constant

(III) **Laboratory**

- (Dry lab) Calculation of values for Entropy and Free Energy for reactions for which the Keq was determined by the students in a previous laboratory activity

## *Electrochemistry (2 weeks)*

(I) **Main Concepts**:

- Redox Reactions
- Balancing Redox reaction
- Voltaic cells
- Cell potential (emf)
- Electrode potentials and spontaneity

- Standard Reduction potential
- Nernst equation
- Electrolytic cells. Electroplating
- Corrosion

(II) **Performance Objectives**:

- Recognize redox reactions
- Assign oxidation numbers to atoms in a reaction
- Write the two half-reactions
- Balance redox equation using the half-reactions method
- Identify the element been reduced and the element being oxidized
- Identify the oxidizing agent and the reducing agent
- Balance redox reaction in acidic and basic conditions
- Draw the diagram, with label, of electrochemical cells, both voltaic and electrolytic
- Calculate the cell potential from electrode potentials
- Predict the spontaneity of a redox reaction using electro potentials
- Calculate G°, E° or Keq for a redox reaction using Nernst equation
- Calculate time, current or amount of substance produced during electrolysis

(III) **Laboratory**

- Electrochemical cells
- Analysis by redox titration: Analysis of Hydrogen Peroxide and analysis of Iron in a supplement tablet
- Electroplating an object to calculate the value of the Faraday constant

## *Atomic Structure and Periodicity (1 week)*

(I) **Main Concepts**:

- Electromagnetic radiation: frequency, wavelength and energy
- The nature of light. De Broglie equation
- The Bohr model of atomic structure
- Line spectrum versus continuous spectrum
- Quantum Theory. Quantum numbers
- Electron configurations and the Periodic Table.
- Periodic Trends: atomic and ionic radii, electron affinity, energy of ionization
- Nuclear Chemistry

(II) **Performance Objectives**:

- Diagram and label the waves produced by electromagnetic radiation
- Correlate frequency, wavelength, energy, and speed of light
- Describe the photoelectric effect and Plank Hypothesis
- Describe the main ideas behind the Bohr model and its limitations
- Explain the differences between line and continuous spectra
- Describe the main ideas of the Quantum model of the atom
- Describe the quantum numbers and their range of values
- Describe the shape of orbitals
- Describe the four basic principles used in writing the electron configuration of an atom
- Write the electron configuration using symbolic notation and orbital diagrams
- Understand the reasons behind the exceptions to the electron configurations
- Describe the variations in atomic radii across the PT and within families
- Describe and calculate the Effective Nuclear Charge (Z)
- Explain the variations in atomic radii within a period as a functions of Z

- Describe the variations in electron affinity across the PT and within families
- Describe the variations in energy of ionization across the PT and within families
- Correlate atomic radii and reactivity
- Correlate electron affinity, and energy of ionization with reactivity
- Explain the observed changes in successive ionization energies for a given atom and relate them to the oxidation number
- Arrange ions by size in an isoelectronic series
- Define isotopes
- Describe the composition of stable and unstable isotopes
- Describe the types of radiation: alpha, beta, positron emission, and electron capture
- Predict the products of nuclear reactions
- Describe the principles of a Mass spectrometer

(III) **Activities**

- Observation of line and continuous spectra for white light and several gases (Ne, He, H, Ar).
- Flame test of a collection of ionic compounds

## *Chemical Bonding and Molecular Geometry (1 week)*

(I) **Main Concepts**:

- Types of chemical bonds: ionic, covalent, intermolecular
- The octet rules and its exceptions
- Electronegativity and bond polarity
- Structural formulas. Lewis structures
- Resonance structures. Formal charge
- Bond enthalpy
- Basic molecular shapes. Role of non-bonding electrons.
- Valence-bond theory. Hybrid orbitals

(II) **Performance Objectives**:

- Define ionic, covalent and intermolecular
- Explain the octet rule
- Explain the exceptions to the octet rule
- Describe the variations in Electronegativity values across the PT and within families
- Describe the nature of the covalent bond in terms of electron cloud overlap
- Predict the polarity of a covalent bond based on the Electronegativity values
- Draw the structural formulas for molecular compounds with single, double and triple bonds
- Draw the structural formula for polyatomic ions
- Define resonance structures
- Draw possible resonance structures for a single compound
- Identify the most stable structure from a collection of possible resonance structures using the concept of Formal charge
- Compare the value of enthalpy for different bonds
- Calculate enthalpy of a reaction using bond enthalpy values
- Define electron domains
- Draw the geometry of the electron domains
- Relate electron domain geometry and molecular geometry
- Understand the effect of electron domains in determining the molecular geometry
- Predict the polarity of molecules based on the polarity of the bonds and the

molecular shape.
- Define hybrid orbitals
- Describe the different types of hybridization.
- Determine the type of hybridization based on the molecular geometry
- Describe sigma and pi bonds
- Explain the concept of delocalization and provide examples

(III) **Activity**
- Construction of molecules using Molecular Models to determine the molecular shape. Correlation between molecular and electron (orbital) geometries, and between geometries and Lewis structures

## *Intermolecular Forces and States of Matter (1 week)*

(I) **Main Concepts**:
- States of Matter based on the relative strength of the Intermolecular Forces
- Types of intermolecular Forces (IMF)
- Physical properties and strength of IMF
- Phase changes
- Vapor pressure and boiling point
- Phase diagrams

(II) **Performance Objectives**:
- Define the three basic states of matter on the basis of the strength of the intermolecular forces
- Describe the basic types of intermolecular forces
- Draw hydrogen bonding between water molecules
- Correlate Boiling Point and Dipole Moment for molecule with similar molecular weights
- Correlate Boiling Point and molecular weight of gases
- Correlate boiling point and strength of IMF
- Correlate Viscosity and Surface Tension of liquids with strength of IMF
- Describe Phase changes at the molecular level in terms of IMFs
- Define vapor pressure.
- Correlate vapor pressure and strength of IMF
- Draw a generic phase diagram and identify the three states of matter
- Locate the multiple boiling points, and melting points.
- Locate the triple point
- Explain what the triple point represents
- Identify and explain the critical point.
- Provide examples of applications of the critical point

(III) **Laboratory**
- Evaporation and intermolecular attractions

## *The nature of Gas Systems (1 week)*

(I) **Main Concepts**:
- Properties and characteristics of gases
- Pressure. Units. Barometers and manometers.
- Gas Laws. Ideal gas
- Kinetic Molecular Theory

- Molecular Effusion and Diffusion
- Real gases versus Ideal gases

(II) **Performance Objectives**:
- Define the characteristics of gases in terms of kinetic energy and IMF
- Define pressure
- Perform conversion between different units of pressure
- Relate volume, pressure, temperature and moles of a gas using the different gas laws
- Calculate the volume, pressure, temperature and moles of a gas under various conditions
- Define Partial pressure
- Describe the method of collecting gases over water
- Describe the Kinetic Molecular Theory as it applies to gases
- Describe the differences between molecular effusion and diffusion
- Calculate the relative rate of effusion of two gases with different molecular mass
- Compare real gases and ideal gases
- Identify the correction factors introduced in the Van Der Waals equation.

(III) **Laboratory**
- Determination of the value for the ideal gas R constant.
- Determination of the Molecular Mass of a Compound – The Dumas Bulb Method

## *Solutions and Colligative Properties (1 week)*

(I) **Main Concepts**:
- Mixtures and Solutions
- Energy of solution
- Solution and spontaneity inn the formation of solutions
- Solubility: saturated and supersaturated solutions
- Factors affecting solubility
- Colligative Properties: Freezing point, Boiling Point, Osmotic Pressure
- Colloids
- Surfactants

(II) **Performance Objectives**:
- Define solutions
- List the different types of solutions
- Recognize the IMF between solute and solvent
- Recognize the bond breaking and formation in the process of dissolving
- Determine the Spontaneity of the process of dissolving
- Definition of the different units of concentration
- Interconversions between units of concentration
- Define solubility.
- Define unsaturated, saturated and supersaturated solutions
- List the main factors affecting solubility
- Henry's Law: Definition and applications
- List the main Colligative properties of solutions
- Raoult's Law: Definition, and applications
- Correlate concentration and change in boiling and freezing points
- Correlate phase diagrams and changes in bp and mp
- Define osmotic pressure

- Recognize the importance of osmotic pressure in biological systems
- Use of osmotic pressure in the chemistry lab: reverse osmosis
- Define Colloids.
- Provide examples of colloids
- Define hydrophobic and hydrophilic
- Define surfactants.
- Provide examples of surfactants

(III) **Laboratory**

- Using Freezing-Point Depression to Find the Molecular Weight