Learning Outcomes
Department of Chemistry and Biochemistry

Chemistry Major (common electives, alternatives possible)
Molecular Synthesis Major

This document outlines overarching learning objectives for undergraduate students majoring in Chemistry or Molecular Synthesis in the Department of Chemistry and Biochemistry at UC San Diego. The table below lists a specific goal with corresponding broad objectives and notes the courses in which the goal is introduced to students (initial assessment) as well as with one or two later courses wherein students may be further assessed. Note that the last of the general goals, M, does not appear as a column, because it refers to an objective that applies more or less equally to all goals and can be assessed only after students graduate.

Broad Goals or Learning Objectives:

A. Have firm foundations in the fundamentals and applications of current chemical theories for the physical world.

B. Use molecular understanding in fields that are based upon chemistry: biology, environmental science, and engineering.

C. Be skilled in problems solving, critical thinking, and analytical reasoning.

D. Know the proper procedures and regulations for safe handling and use of chemicals and follow the proper procedures and regulations for safety when using chemicals.

E. Design, carry out, record, and analyze the results of chemical experiments.

F. Use a broad variety of modern instrumentation and classical techniques in the course of experimentation.

G. Interpret and evaluate results critically. Identify and quantify uncertainties in measurements and limitations in methodologies.

H. Use modern library searching and retrieval methods to obtain information about a topic, chemical, chemical technique, or an issue relating to chemistry, going beyond textbooks and common handbooks.

I. Communicate results of work to chemists and non-chemists, including respect for the tradition of careful citation of prior contributions, both orally and in effective writing.

J. Collaborate effectively as part of a team to solve problems, debate different points of view, and interact productively with a diverse group of team members.

K. Understand the ethical, historic, philosophical, and environmental dimensions of problems and issues facing chemists.

L. Be able to identify and solve chemical problems and explore new areas of research.

M. Find gainful employment in industry or government, be accepted at graduate or professional schools, or find employment in school systems as instructors or administrators.

Specific Goals:

Learning Objective	Where Taught	A	B	C	D	E	F	G	H	I	J	K	L	Where Assessed
Meet the objectives of introductory calculus as specified by the Department of Mathematics	Math 20A/B/ C/D	✓		✓										Many
Meet the objectives of elementary physics as specified by the Department of Physics	Physics 2A/B/D 2CL	✓		✓										105A
Recognize elemental symbols and place the more common elements on a Periodic Chart	6A	✓	✓											All
Use a Periodic Chart to predict elemental and atomic properties, such as electronegativity, size, state of matter, likely reaction partners	6A	✓												6C 120A
Count molecules in units of moles and write balanced chemical reactions in terms of mole numbers	6A	✓		✓										All
Recognize a limiting reagent, calculate amounts of reaction product and yield	6A	✓		✓										6BL
Recognize the differences among materials that are metallic, ionic, or covalently bonded	6A	✓	✓											120A
Use molecular orbital theory to explain differences among second row diatomic molecules	6A	✓												140A
Appreciate the role of nonbonding interactions, in particular with respect to solubilities	6A	✓	✓											6C
Use quantum mechanical descriptions for electronic orbitals and molecular symmetry principles to describe chemical bonding	120A	✓												120B 124
Use Lewis Diagrams to predict molecular connectivity	6A	✓												140A
Use valence shell repulsion theory to predict shapes of symmetric molecules	6A	✓												120A 140A
Sketch 1s, 2s and 2p atomic orbitals and combine them to interpret sp3 ,sp2 and sp hybrid orbitals.	6A 140A	✓												140A 156
Sketch molecular orbitals (bonding and antibonding) for any 2-carbon molecule, with peripheral atoms, showing the mathematical signs of the lobes and approximate relative energies. Sketch pi molecular orbitals of conjugated systems. Sketch the structures of carbocations, carbanions and radicals.	140A	✓												140B 156
Understand bond formation and bond energies, and predict which bonds are weak and which are strong.	140A	✓												140B 156
Extend valence shell repulsion theory to treat strain	140A	✓												140B 156
Use a simplified crystal field theory to rationalize structure and reactivity of transition metal complexes and their colors when dissolved in water	6C	✓												120A
Use ligand field theory and other quantum methods to predict the molecular structures of transition metal complexes and extend this to organometallics	120B	✓												124 223
Solve the Schroedinger Equation for a 1-d harmonic oscillator to derive eigenvalues and eigenfunctions. Note the equal-spaced energy levels	126 133	✓		✓										230
Solve the Schroedinger equation for a 1-d square well and for a rigid rotor, noting that energy levels become more widely spaced at high energies	126 133	✓		✓										230

Solve the Schroedinger Equation for a Coulomb potential, noting that energy levels are spaced more closely at high energies	126 133	✓		✓										230
Explain energies and transitions for simple atoms at an intermediate level	126 133	✓		✓										230
Develop a proper quantum interpretation of bonding for simple molecules	126 133													230
Use and be able to interconvert among the several ways of denoting solutions concentrations	6A			✓										6BL 6C
Use the four colligative properties to calculate concentrations or molar masses, depending on known information.	6A	✓		✓										6BL 100A
State the 4 great laws of thermodynamics and explain why they are considered great	6B	✓	✓											127 131
Distinguish state functions from such non-quantities as heat and work	6B	✓												127 131
Manipulate partial derivatives of state quantities using relations such as the Maxwell relations	127 131	✓		✓										230
Calculate the idealized maximum efficiency of a heat engine or a refrigerator as deduced from a reversible Carnot cycle	127 131		✓	✓										
Calculate the maximum efficiency of a less-than-ideal reversible cycle, such as those of Otto or Diesel	127 131		✓	✓										
Identify the fallacy in the creationists' erroneous assertion that evolution is inconsistent wit the Second Law	6B	✓	✓											127 131
Explain why it is that reactions that heat their surroundings are likely to be spontaneous and why it is that even some that cool their surroundings can be spontaneous.	6B	✓												127 131
Use Hess's Law to combine thermal energies for chemical reactions when one combines consecutive atomic combinations	6B	✓	✓	✓										127 131
Use tables of free energies to compute equilibrium constants	6B	✓	✓	✓										127 131
Evaluate equilibrium constants from information about concentrations or partial pressures; or use equilibrium constants to deduce concentrations or partial pressures at equilibrium, given some initial condition	6B	✓		✓										127 131
Distinguish strong and weak acids and bases	6B	✓	✓											140A
Convert between the pH scale and concentrations of protons or proton acceptors in aqueous solution	6B		✓	✓										6BL 100A
Carry out titrations to determine the pH of an unknown aqueous solution to acceptable accuracy and precision.	6B 6BL			✓	✓	✓	✓	✓						100A
Generalize the concept of a titration to any chemical or biochemical measurement	114A 112A		✓	✓										100BL 112B
Desire and prepare a pH buffer of required pH and ionic strength	6B 100A		✓		✓	✓		✓						112A
Compare and contrast Arrhenius, Bronsted, and Lewis acids	6B	✓												140A
Write balanced equations for oxidation-reduction reactions, including the participation of solvent water	6C	✓	✓	✓										100A 120A
Use redox tables to predict the spontaneous direction for reactivity in redox reactions, and have some intuitive notions even without a table of potentials	6C	✓	✓											120A

Calculate the reversible emf expected for an arbitrary redox reaction, using tables, for any combination of concentrations of solutes and pressures of gasses	6C			✓										127 132
Deduce reaction rate laws and rate constants from initial rate data	6C	✓		✓										127 132
Transform data from measurements of kinetic processes to produce a linear plot and deduce reaction order and rate constants from such plots	6C			✓										127 132 105A
Explain the role of catalysts in a reaction and give some examples	6C	✓												140B
Distinguish addition polymers from condensation polymers and give examples of each.	6C	✓	✓											140C
Distinguish homogeneous and heterogeneous catalysis, and write reaction schemes for each	120B 231	✓	✓											
Recognize and use Michaelis-Menten kinetic scheme	114A 127	✓	✓											116
Derive rigorously the Michaelis-Menten scheme	132 231			✓										
Apply the principles of gravimetry to determine the amount of analyte in an unknown sample	6BL			✓	✓	✓	✓	✓						
Titrate a weak acid with a strong base to determine the molar mass, pKa, and identity of the acid	6BL			✓	✓	✓	✓	✓						
Determine the specific heat of a metal, the heat of fusion of water, and the heat of neutralization of an acid-base reaction via coffee-cup calorimetry	6BL			✓	✓	✓	✓							
Use oxidation-reduction titration to determine the oxalate content in the iron oxalate complex	6BL			✓	✓	✓	✓	✓						
Synthesize an iron (III) oxalate complex	6BL				✓	✓	✓							
Use spectrophotometry to determine the iron content in the iron oxalate complex	6BL			✓	✓	✓	✓	✓						
Understand and follow a semimicro qualitative analysis scheme to characterize a mixture of common metal ions	6BL			✓	✓	✓	✓							
Investigate the atomic emission spectra of various elements	6BL					✓	✓							
Maintain a clearly written lab notebook as a permanent record of experimental results	6BL					✓			✓					
Write a simple report in standard format emulating publication in a science journal	6BL									✓				100A All labs
Apply knowledge of chemical bonding and synthetic laboratory skills to synthesize, analyze, and characterize inorganic chemical compounds.	123				✓	✓	✓							223 225
Demonstrate skill using a computer spreadsheet	100A						✓							105A
Demonstrate proficiency with computer graphing	100A						✓			✓				105A
Characterize reaction kinetics in a laboratory	100A				✓	✓	✓			✓				105A
Measure chemical equilibria in solution	100A			✓	✓	✓	✓	✓		✓				
Use electrochemical techniques and ion selective electrodes to determine ion concentrations	100A			✓	✓	✓	✓	✓		✓				
Use column chromatography to separate components of a mixture	100A			✓	✓	✓	✓	✓	✓	✓				100B Others
Use gas chromatography to separate mixtures, using several different detection strategies, including mass spectrometry	100BL 143B 143C		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Use high performance liquid chromatography to separate mixtures	100A 100BL		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		100B
Demonstrate proficiency in statistical analysis and error estimation beyond what was learned in the	105A 100BL	✓	✓			✓		✓		✓		✓		100BL 105B

lower labs														
Use spectral information and heat capacities to calculate partition functions	132	✓		✓										233
Use partition functions to calculate equilibrium constants	132	✓		✓										232
Draw conformations of alkanes and cycloalkanes (Newman projections, wedge/dotted-line structures). Graph the relation between conformation and potential energy for these molecules. Predict preferred conformations, including those of substituted cyclohexanes. Calculate the ratio of conformers based on relative energies.	140A	✓		✓										140B 156
Explain how conformations around bonds translate into global shape changes and dictate the overall structure of big molecules, emphasizing relevancy for biological structures.	140B	✓	✓											140C 114A
Recognize strain in various conformations and predict effect on stability and as a driving force for reactivity and rearrangements.	140B	✓		✓										143B 157
Define and recognize stereoisomer, enantiomer, diastereomer, conformation, configuration, meso, epimer, resolution. Recognize inversion, retention and racemization. All these for any molecule.	140A	✓												140B 140C
Sketch a molecule with a chiral center so as to show unambiguously the configuration using both Fischer projection and perspective drawing. Determine the configuration (R or S) of any chiral center from a perspective drawing.	140A	✓												140B 156
Calculate “specific rotation” from the experimental optical rotation and concentration.	140B			✓										143C
Determine the configuration (E or Z) of any double bond.	140A	✓												140B
Describe the formation and relative stabilities of carbocations as related to hyperconjugation.	140A	✓		✓										156
Convert IUPAC names of simple molecules to chemical structures.	140A 140B								✓					140B 140C
Write contributor structures to a resonance hybrid for simple molecules and rate the importance of each contributor.	140A	✓		✓										140B 140C 156
Analyze inter and intramolecular forces and estimate solubility, melting point and boiling point. Describe the molecular events occurring during the processes of dissolving, melting and boiling.	140A	✓												143A
Explain the unique role of water as a solvent.	6A	✓	✓											140A
Use the unique solvation properties of water to predict or retrodict organic molecular structure with emphasis on molecules of biochemical interest	140A 140C	✓	✓											140C 114A
Estimate relative acidities and basicities of organic compounds based on estimation of the stabilities of their conjugate base and acid. Calculate the pH of a solution of a weak acid or base from the analytical concentration and Ka. Calculate the proportions of protonated and non-protonated species at a given pH.	140A 140B	✓	✓	✓										140C 156
Locate reactive sites within a molecule and draw correct electron-pushing arrows for reactions based on electronic properties and structure instead of rote memorization of mechanisms.	140A 140B	✓												140C 154

Explain by words and equations the factors affecting the rate of a chemical reaction, including temperature. Analyze kinetic data and determine the order of a reaction. Validate reaction mechanisms by comparison with kinetic data.	140A 140B	✓												140C 156
Distinguish between kinetic and thermodynamic products of reactions. Explain reasons for obtaining one product rather than the other.	140B 154	✓												140C 154
Use the concepts of delocalization and resonance for estimation of bond lengths, electronic distribution, stability, aromaticity, basicity, acidity and reactivity.	140A 140B	✓												140C 154
Draw conclusions about a reaction mechanism from the stereochemistry of the products. Given a proposed mechanism for a reaction, predict the stereochemistry.	140B 140C 154	✓		✓										140C 154 156
Define and recognize regioselective, stereoselective and stereospecific reactions. Describe resolution of a racemic mixture by converting it to a diastereomeric mixture.	140A			✓	✓	✓								140B 156
Understand and explain the importance of chiral recognition in biological systems.	140A 140C		✓											140B 114B
Distinguish nucleophiles from electrophiles and list examples of each. Write chemical equations to describe the currently accepted mechanism(s) for major reactions: radical, SN1, SN2, E1, E2, electrophilic addition, electrophilic substitution, conjugate addition, addition-elimination, pericyclic. Explain how each mechanism is deduced from experimental kinetic data and stereochemistry of the products. Be able to specify structures and energetics of intermediates in multistep reactions.	140A 140B 155	✓												140C 154 156
Describe how the terms oxidation and reduction are used in organic chemistry.	140A	✓												143A
Recognize and predict rearrangements of carbocations.	140A 156	✓												140B 154
Identify all major functional groups and the reactivity of each.	140A 140B	✓												140C 152 155
Identify the functional groups prominent in reactions that biomolecules undergo.	140C		✓											114B
Conduct a retrosynthetic analysis of a given compound and outline the forward steps and reagents that are required	140B 140C 152				✓	✓	✓	✓						140C 155
Be aware of the pervasiveness of organic substances in the environment.	140A 149B		✓									✓		140B 140C
Identify and discuss some of the common polymers and macromolecules, at a level more soils than in C.	140C		✓									✓		114A 114D
UV-VIS: Use the terms chromophore, molar absorptivity, wavelength at maximum, transition, pi - pi*, n - pi*.	140B						✓							143D 158
UV-VIS: Use UV-VIS data to calculate concentrations and assist in determining chemical structure.	6BL 100A 140B			✓		✓	✓							143D 158
UV-VIS: Explain the effect of conjugation on the absorption wavelength by sketching the molecular orbitals and relative energies.	140B													143A
IR: Describe the molecular transitions responsible for the infrared absorption.	140B	✓												143A 143B

IR: Use the characteristic absorption frequencies (data provided) of functional groups to assist in determining the structure of an unknown compound.	143A 143C			✓		✓		✓						143C 146
IR: Predict how electronic and structural factors affect the infrared absorption of functional groups, particularly carbonyls.	140B 143A	✓		✓			✓							143B 140C 158
IR: Explain the connection between infrared absorption and the "greenhouse effect".	140A 149A		✓									✓		140C 173
NMR: Magnetic resonance of protons and carbon: Identify the number of non-equivalent protons and carbons in a given molecule based on symmetry. Assign peaks of an NMR spectrum to likely chemical environments. Identify the relative numbers of protons of an unknown using integration. Identify the presence of neighboring protons from splitting patterns and coupling constants. Use NMR spectrum to elucidate the structure of an unknown compound.	140B			✓			✓	✓						143B 140C 158
NMR: Predict the NMR spectrum from a structure (number of peaks, multiplicity and chemical shift).	140B			✓			✓	✓						143B 143C
NMR: Use the proton decoupled ^{13}C NMR spectrum to assist in the determination of the structure of an unknown compound.	140B			✓			✓	✓						143B 143D 158
NMR: Distinguish solvent and reference NMR signals from that of the sample	140B							✓						143B 143D
NMR: Understand and explain conformational averaging in NMR spectra.	140B	✓					✓	✓						143C 158
Characterize reaction products by spectroscopic methods, as available.	143A 143B	✓				✓	✓							143C 143D
Document data and observation accurately.	6BL 143A					✓	✓							All labs
Lab: Carry out a task with a proficient and confident manner while working alone	6BL 143A				✓	✓								100A
Lab: Work as a member of team in an efficient manner toward a common goal	105A 143D				✓	✓	✓	✓	✓	✓	✓	✓		100BL
Lab: Maintain safe practices for oneself and others	6BL				✓	✓								All labs
Lab: Minimize waste and dispose of waste legally and correctly	6BL 143A				✓	✓								All labs
Lab: Relate laboratory procedures, whether synthetic or analytical, to underlying theory	105A 143A	✓				✓	✓							All labs
Lab: Demonstrate and use subsequently: Recrystallization, extraction, evaporation, TLC, column chromatography, distillation.	143A				✓	✓	✓							143B
Lab: Set up and use apparatus to carry out a variety of reaction types	143A 143B				✓	✓	✓							123 143D
Lab: Demonstrate when and how to reduce hazards by using hoods, glove boxes, or oxygen-free techniques	6BL 143A				✓	✓								123 143B 143D
Lab: Document procedures and results completely, accurately, and with complete honesty in notebooks kept to professional standards	6BL 100A 143A					✓			✓	✓				All labs
Operate a variety of laboratory instruments and apparatus for synthesis and for analysis, with explicit direction or, eventually, following written manuals.	100A 105A 143A				✓	✓	✓	✓						All labs
Analyze experimental data, using proper statistical methods and construction of graphs that re effective in communicating results to others	6BL 100A					✓		✓	✓	✓				105A All labs
Distinguish precision and accuracy. Distinguish	100A					✓		✓		✓	✓			100BL

systematic from random error and blatant mistakes. Identify these in reports and present quantitative limits on error when it is possible to do so.	105A												Others
Search and retrieve chemical information from various databases.	105A 143C				✓	✓			✓				143D Others
Read, analyze and critically evaluate journal papers in various subfields of chemistry	105A Et al.								✓			✓	143D Others
Write scientific reports in a concise, organized and effective style	6BL 100A 143A/B									✓		✓	105A 100BL 143C/D
Report scientific findings and inferences in oral presentations in clear and organized fashion, using visual tools, mostly PowerPoint® computer methods	105A									✓		✓	100BL 143D
Incorporate into one's own repertoire a broad familiarity with useful synthetic reactions for organic chemistry	152	✓											
Be able to propose methods of preparation of carbon-carbon bonds. Be able to formulate oxidation reduction sequences for chemical transformations. Be familiar with the repertory of reagents and protecting groups	152	✓		✓									
Know, decipher, and use mechanisms of a wide variety of organic reactions	154	✓		✓									
Recognize relation between molecular structure and reactivity	140A 154	✓		✓									154
Plan synthetic routes that are both effective and economic, for complex molecules involving control of stereochemistry.	155	✓	✓	✓	✓	✓			✓			✓	✓
At an advanced level, be proficient with techniques for determing physical properties of organic molecules	156			✓		✓	✓	✓	✓				
Apply molecular-orbital theory to questions of stability and chemical reactivity	156	✓											
Formulate pathways for biosynthesis of natural products explain how molecules interact with and recognize each other	157	✓	✓	✓									
Propose molecular structures consistent with spectroscopic data	143C 158			✓			✓	✓	✓	✓			
Explain the theory of origin of life	114A	✓		✓								✓	
Describe the difference between eukaryotic and prokaryotic cells	114A	✓	✓										
Recognize the 20 amino acids and explain the differences in their chemical properties.	114A	✓											
Explain and sketch the periodic arrangements of secondary structures within a protein fold	114A	✓											
Understand the packing of secondary structure units to form a tertiary fold	114A	✓											
Identify the packing of tertiary folds to form specific quaternary structures	114A	✓											
Use analysis of hydrophobic interactions and properties of water and how they influence protein folding in solution and in membranes	114A	✓											
Distinguish and explain negative and positive cooperativity and allosteric interactions	114A	✓											

Describe the organization of the membranes and the influence of specific chain properties on the fluidity of the membrane	114A	✓												
Know that specific classes of proteins called enzymes are catalysts of chemical reactions	114A	✓												
Recognize and use Michaelis-Menten kinetic scheme	114A			✓										
Review the properties of buffers and concept of pH and explain how solution pH can influence protein stability and enzyme kinetics	114A	✓		✓										
Distinguish competitive, non-competitive, and uncompetitive inhibitors affect observed rates of reactions	114A	✓		✓										
Explain how inhibitors can be used as drugs.	114A		✓											
Describe the structure and properties of DNA in terms that take advantage of insights provided by organic chemistry.	114A	✓												
Independent research is encouraged but not required	199				✓	✓			✓	✓	✓		✓	