Pedagogical Inquiry Grant:
Updating Whitman's General Chemistry Curriculum

Final Report

2021-22 Academic Year

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Executive Summary

The committee met weekly over the 2021-22 academic year. The first months focused on studying the advantages and disadvantages of various General Chemistry curricula and other possible adjustments to the course, followed by a comprehensive review of every specific topic covered in the course to decide what the essential content of the course is and what can be considered optional. The committee also solicited feedback from departments who require General Chemistry for their courses, including geology, biology, and BBMB. The committee then approved several substantial changes to the course. Among these include adopting a new 'Atoms First' curriculum, a new open-access textbook (from OpenStax), and a new online homework system (Aktiv Chem101). These modifications are expected to result in an improved student experience in a variety of ways. The committee developed a model course calendar based on these changes and Prof. Machelle Hartman developed an accompanying model calendar for the General Chemistry laboratory course to align with the new lecture calendar. The committee discussed various strategies for improving accessibility and inclusion in the course and will pilot some of these ideas in 2022. To further assess the impact of these changes, the committee worked with Prof. Ginger Withers as the coordinator of the Student Consultant Program to hire students who were enrolled in the previous General Chemistry model in 2021 as student consultants for the 2022-23 academic year for every section of Chemistry 125. Overall, this update represents some of the largest changes to the General Chemistry curriculum at Whitman in decades and highlight the success of this Pedagogical Inquiry Grant.

Report

The General Chemistry PIG committee met weekly from September 2021 through May 2022 to reconsider all aspects of the general chemistry (GenChem) lecture sequence (CHEM 125-126), and to some extent how changes to these courses impact other aspects of the chemistry curriculum. The first part of the fall semester was focused on general discussions about how to approach a major review of the GenChem sequence, including priorities, strategies, and common principles. Among the priorities and strategies that were identified include (1) building a course that would support all students, including those with weaker math and science backgrounds coming out of high school, and students who are underrepresented in the sciences at Whitman, (2) acknowledging that no course design is going to be perfect for all students and that even significant changes likely will not result in a 'perfect class,' (3) that we would consider cutting back some of the topics covered in the course, but that we wanted to ensure that course still met the needs of the biology, BBMB, and geology majors, (4) that we would eventually need to discuss the topic of the course at a fine-grain level to decide what is essential and what could be cut, and (5) the essential topics and skills in the course are those that we directly assess during the semester (perhaps not every year, but regularly).

Following these discussions about how to approach the review, the committee spent a substantial portion of the fall researching and discussing the advantages, disadvantages of a variety of curricula and approaches for teaching General Chemistry, including how they would fit into Whitman's unique curricular environment. Among the pedagogical options studied were the currently-used 'reactions first' and the alternative 'atoms first' curricula, the 'chemistry of life, the universe, and everything' (CLUE) curriculum, alternative ordering of the courses (such as splitting organic chemistry to bookend general chemistry, so students would start with the first semester of organic chemistry), and some sort of combined biology-chemistry course. Drastic changes to the pedagogy of the course, such as transition to a fully flipped classroom, were also discussed. During this stage the committee solicited feedback from departments and programs that include general chemistry as pre-requisites for their courses (biology, geology, BBMB) about what aspects of general chemistry are critical to their curricula. At the end of the fall semester the committee surveyed all of the students finishing the first semester of General Chemistry about their course experience (see Fig. 1), which was particularly enlightening because the faculty teaching the course had opted to adopt a number of significant changes after the online teaching during the pandemic (e.g. different online homework platforms, some flipped classes vs. some active lectures). The full results of this survey are available upon request from the chemistry department.

Homework Platform		If you have an opinion, which HW?			
		Mastering Chemistry	Chem101	Neither	**Total**
125 Section	A (Russo)	90%	0%	10%	***100%***
	B (Dunnivant)	59%	18%	24%	***100%***
	C (Boland)	79%	16%	5%	***100%***
	D (Machonkin)	69%	6%	25%	***100%***
	E (Barrows)	0%	95%	5%	***100%***
	Total	60%	27%	13%	***100%***

Fig. 1. Example survey results from the fall semester

The next step was to undergo a comprehensive review of every specific topic covered in the course to decide what the essential content of the course is and what can be considered optional. Using a combination of our current teaching materials and the ACS recommended content map for general chemistry, each member of the committee independently classified each topic as essential, optional material and/or an optional extension/connection to another field, or optional/unnecessary. While many topics were unanimously categorized, any topic that were categorized in different ways was discussed until a consensus was reached. The final list of topics and their categorization is attached in Appendix 1.

Once the comprehensive review was complete, the committee felt like it had reached consensus about the best changes to support our students within the constraints of the available resources and taking into consideration our unique situation at Whitman. The following motions were voted on by the committee and all passed unanimously; they represent the core of the changes adopted by the committee during the review:

1. We move to adopt an ‘atoms first’ model for the general chemistry (Chem 125-126) curriculum, pending confirmation from Machelle that we can make the corresponding labs work effectively with the ‘atoms first’ model.
2. We move to drop Pearson products (Tro and MasteringChemistry) as the primary resources for the general chemistry (Chem 125-126) courses.
3. We move to adopt OpenStax Chemistry and Chem101 as the primary text and homework system for the general chemistry (Chem 125-126) courses. Faculty can also write their own homework/quizzes to give in class and/or on Canvas.
   *We expect that adopted a free, open-source textbook will save each student $130-$150, with an overall savings of over $20,000 to the student body each year.
4. We move to continue with our historical effort to maintain consistency between sections of general chemistry, however expressing support for individual faculty to run pedagogical ‘experiments’ in their courses that involve changing some aspect(s) compared to the other courses. The department does not need to approve these experiments, but the faculty undertaking the experiments should provide the rest of the faculty in the department a brief explanation of the change(s) prior to the beginning of the course and a summary of the results of the experiment at the conclusion of the course.
   *Explanation: It will help the rest of the department know how to respond effectively/correctly to students from ‘experiment sections' if everyone knows what’s different in those sections and will also enable the full department to learn from the experiences of each other’s teaching experiments.

After these votes, the committee focused its efforts on determining how to best implement the changes. Transitioning from the current ‘reactions first’ curriculum to the ‘atoms first’ curriculum was the change that required the most effort. The committee developed multiple potential course calendars utilizing the new curriculum; the biggest difference among them was which semester the chapter on solutions vs. thermodynamics would be taught. This decision was discussed with the geology department, since they only require one semester of general chemistry so moving topics between semesters affects the content their students see. Based on the relative merits the committee opted to include thermodynamics in the spring, recognizing that this makes the spring semester more quantitatively challenging that the spring but allows students to develop study skills in the fall. Alongside the lecture course calendar, Prof. Machelle Hartman also developed model calendars for the associated lab courses based on the new ordering of topics; ensuring that the lab course would still run smoothly was a priority during these discussions. The lecture calendar that was adopted for the course is attached as Appendix 2.

The last significant task that the committee undertook was to consider strategies for increasing accessibility and inclusion in the course. Among the ideas that were discussed that the committee plans to pilot in the coming years include: incentivizing/assigning study groups early in the semester; developing additional in-class, small-group workshops; possibly assigning semi-random group assignments. Perhaps the largest of the proposed ideas is shifting the current companion course (CHEM 111) for CHEM 125 to focus more on study skills and general support for the course, while adding a spring companion course for CHEM 126 that focuses more on quantitative support, which is currently emphasized in the fall. The committee expects this to be particularly necessary given the shift of thermodynamics to the spring semester and is piloting this idea as a special topics course in the spring of 2023.

Finally, the committee discussed various ways to assess the effects of the proposed changes and decided that the best option is to hire student consultants who have taken the current version of the general chemistry sequence, and who will sit through significant portions of the new version and chat with students enrolled in the new version to provide a student perspective on how these changes are impacting student learning and the student experience. The committee would particularly like to thank Prof. Ginger Withers for her help in organizing the student consultant program.

Overall, this update represents some of the largest changes to the General Chemistry curriculum at Whitman in decades and highlight the success of this Pedagogical Inquiry Grant.

Budget Report

The committee requested stipends for eight faculty. One faculty member rolled off the committee at the end of the fall semester, but another joined the committee for the spring, so the full budget for stipends and OPE was used. Due to the ongoing pandemic, all meetings were held virtually so the refreshments budget was not used at all. The committee also did not find a need for student assistants over the course of the committee's work, instead opting to utilize the student consultant program once the changes are implemented, so the student assistant budget was also not used.

Appendix 1. Topic List for CHEM 125-126

Bolded items were deemed essential content for the course and are expected to be regularly assessed. Purple items are option extensions/connections to other fields. Non-bolded items are topics that were previously taught be at least some faculty that are optional and/or unnecessary.

Topic	Detail
Tro Chapter 1 Properties of Matter	**Bolded topics are essential for assessment**
	Define matter
	States
	Elements vs. compounds
	Pure substances vs. mixtures
	Intensive vs. extensive properties
Matter undergoing change	
	Physical vs. chemical change
	Work vs. heat
	Heat vs. temperature
	Kinetic vs. Potential Energy
Measurements	
	English vs. metric system
	7 base units in SI system
	Conversion between metric units
	Conversion between English and metric units
	Dimensional Analysis
	Uncertain digits
	Precision in a number (how many decimal places)
	Scientific notation
	Significant figures in addition/subtraction calculations
	Significant figures in multiplication/division calculations
	Significant figures in logarithm/antilogarithm calculations
	Precision in a group of measurements
	Accuracy in a group of measurements
	Temperature conversions between C and K
	Temperature conversions between C and F
	Density Calculations
Tro Chapter 2 Laws & Theories	
	Law Conservation Matter
	Law Constant Composition
	Law Multiple Proportions
	Dalton's Atomic Theory
Atomic Structure	
	Radiation (alpha, beta, gamma)
	Thomsen Cathode Ray Tube
	Thomsen Plum Pudding Model
	Millikan's Oil Drop Experiment
	Rutherford Gold Foil Experiment
	Chadwick discovery of neutron
	Location, mass, charge of p, n and e
	Element vs. isotope
	Atomic mass calculation (fractional abundance)

Periodic Table	
	Oxidation states for Group A ions
	Metals, nonmetals, metalloids
	Group B and multiple oxidation states
Mole	
	Avogadro's number
	Molar mass vs. atomic mass
	Calculation of molar mass in a compound
Tro Chapter 3 Molecules, Ions	
	Covalent, ionic, metallic bonding
	Formulas: empirical, molecular, structural
	Naming/writing ionic formulas with simple ions
	Naming/writing ionic formulas with polyatomic ions
	Memorizing a list of polyatomic ions (curated list)
	Naming/writing binary molecular formulas
	Memorizing strong acids, including a curated list of weak acids
	Naming hydrates
Percent Composition	
	Calculation of mass of element given mass of compound
	Calculation of percent composition of each element in compound
	Finding empirical formula if given percent composition
	Finding empirical formula from combustion
	Finding molecular formula from true molar mass and empirical formula
Chemical Equations	
	Write a reaction (including states) from a prose description
	Balancing reaction with stoichiometric coefficients
Tro Chapter 4 Stoichiometry	
	Mole ratio
	Conversion of grams of A to grams of B
	Limiting reactant calculation
	Theoretical vs. percent yield
Descriptive Chemistry	
	Combustion reactions
(up vote from Bio)	Mechanism of the greenhouse effect
	Reactions of alkali metal and halogens
	Reactions of alkali metal and water
	Reaction of transition metal with halogen
	Reaction of one halogen with another
	Reaction of halogen with hydrogen gas
Tro Chapter 5 Solution Concentration	
	Solute vs. solvent
	Calculation of mass needed to make a solution of a certain molarity
	Calculation of volume needed from a stock solution
	Define and calculate concentrations in units of "parts per..." (ppt/ppm/ppb)
Solution Types	

	Polarity of water
	Dissolving vs. dissociation
	Strong, weak and nonelectrolytes
Precipitation Reactions	
	Predict products when two soluble ionic compounds are mixed
only the ALWAYS soluble	**Memorize Solubility rules: limited cases of what-is-always-soluble**
	Net ionic equations
Acid-Base Reactions	**This needs to get thought through more carefully**
	Arrhenius definition of acid vs. base (but maybe still introduce H_3O^+)
	Bronsted-Lowry definition of acid vs. base
	Recognize acid-base neutralization
	Recognize polyprotic acids
	Memorize list of strong acids and bases
	Recognize gas-evolution acid-base reactions
	Titration calculations
	What industrial gases are the source of acid rain?
Redox Reactions	
	Definition of redox (using electrons)
	Definition of redox (using O and H)
	Assign oxidation numbers to all atoms in a compound
	Determine the oxidizing and reducing agents
Comparison of Reactions	
	In a list of reactions, determine which are redox, ppt, or acid-base
Tro Chapter 6 Terms	
	Units for force and pressure
	Barometer
Individual Gas Laws	
	Boyle's Law describe
	Boyle's Law memorize
	Charles' Law describe
	Charles' Law memorize
	Origin of the Kelvin scale and meaning of absolute zero
	Avogadro's Law describe
	Avogadro's Law memorize
Ideal Gas Law	
	Memorize Ideal Gas Equation (they will do it on their own)
	Memorize value for R
	Memorize STP for gases
	Memorize standard molar volume
	If given three variables, calculate the fourth using the ideal gas equation
	Calculate a new variable if conditions change (combined gas law)
Dalton's Law of Partial Pressures	
	Use Dalton's Law of partial pressures in calculating either Ptot or Pi
	Use mole fraction in calculating either Ptot or Pi
Kinetic Molecular Theory	
	Memorize postulates of the KMT
	Conceptional picture of KMT

Memorize formula for kinetic energy
Describe relationship between molecular velocity and mass
Distribution of velocities (what is temperature)
Calculate molar mass from root mean square speed
Recognize the difference between effusion and diffusion
T and P conditions where real gases behave most ideally
P conditions where molecular volume cannot be ignored
T conditions where IMF cannot be ignored
Use van der Waals equation in calculations

Tro Chapter 7
First Law of Thermodynamics

Describe the first law of thermodynamics
Describe what a state function is
Calculate the change in internal energy of a system if given heat and work t
Convert between Joules and calories
Calculate heat exchanged using heat capacities
Calculate work of an expanding or contracting gas (P-V work)
Calculate the change in internal energy of a system with calorimetry data

Enthalpy

Define enthalpy from internal energy, pressure, and volume
Calculate heat of reaction using Hess' Law (combining known reactions)
Calculate heat of reaction using standard heats of formation

Tro Chapter 19
Second Law of Thermodynamics

Describe what "spontaneous process" means
Describe what entropy is in terms of microstates
Describe the second law of thermodynamics
Describe the three types of microscopic motion: translation, vibration, rotat
Describe the third law of thermodynamics

Entropy Changes

Predict the sign of an entropy change if given the chemical equation
Calculate the entropy change during a state change
Calculate the entropy change of the surroundings, if given the enthalpy char
Calculate the entropy change of a system using standard molar entropies

Free Energy Changes

Calculate the Gibbs' Free energy change of a system using standard free en
Calculate the Gibbs' Free energy change of a system from delta S and delta
Predict spontaneity using Gibbs' Free energy
From delta S and delta H, determine the relationship between spontaneity a
Calculate q, w, dU, dH, dS, and dG in thermodynamic cycles (isotherms, adia

Tro Chapter 8
Waves and Light

Convert between frequency and wavelength
Describe the diffraction patterns of particles vs. waves
Describe the various portions of EM spectrum in terms of energies

20th C Model of the Atom

Describe line spectra
Use Planck's equation on quantization of light

Memorize Planck's constant
Use Einstein's equation to calculate the energy of a photon
Describe the shortcomings of the Bohr model of the atom
Use deBroglie's equation to calculate the wavelength of an object
Calculate the uncertainty in velocity or momentum given the mass of a parti
Heisenberg Uncertainty Principle concept
Define the allowed values of the principal quantum number
Define the allowed values of the angular momentum quantum number
Define the allowed values of the magnetic quantum number
Define the allowed values of the spin quantum number

Orbitals

Describe the shapes of s, p, d (not f) orbitals

Tro Chapter 9
Aufbau

Describe sublevel energy splitting and why
Predict shorthand electron configurations with a Periodic Table
Identify allowed electron configurations on the basis of the Pauli Exclusion p
Describe how core electrons shield valence electrons
Trend in effective nuclear charge
Predict how electron configurations predict the oxidation states of Group A i
Explain anomalies in the electron configurations of Group B atoms
Electron configs of cation and anions, incld. trans. metals
Describe the difference between paramagnetic and diamagnetic elements

Periodic Trends

Coulomb's law
Describe trend in atomic radius
Describe trends in ionic radius
Rank isoelectronic ions by size
Predict trends in first ionization energy
Explain discontinuities in first ionization energy across a row on the basis of
Trends in successive ionization energies
Predict trends in electron affinity
Explain discontinuities in electron affinity across a row on the basis of electr
Predict trends in metallic character
Predict oxidizing and reducing agents on the basis of where the elements ap
Electronegativity (Pauling or Allen)

Tro Chapter 10
Lewis Dot Structures

Draw Lewis dot structures for Group A atoms
Decribe the octet rule

Ionic Compounds

Classification of bonding

Describe the relationship between lattice energy and electrostatic attractio
Born-Haber Cycle
Rank ionic compounds by increasingly exothermic lattice energy (charge, si
Name the physical properties of ionic compounds

Covalent Compounds

	If given the formula of a molecule or polyatomic ion, draw a valid Lewis stru
	Draw valid LDS for larger molecules if given the connectivity
	Use Pauling's electronegativities to predict if a bond is polar, nonpolar, or io
	Depict resonance structures when appropriate
	Assign formal charges to atoms in a molecule
	Use formal charges to decide which of multiple Lewis structures is reasonab
	Name exceptions to the octet rule
	Draw valid LDS for expanded valence shell compounds
	Describe the differences between covalent network solids and molecular co
Bond Energies	
	Describe how bond energies vary with bond order and bond length
	Use bond energies to estimate the heat of reaction
Tro Chapter 11 VSEPR	
	Predict the electron domain geometries around a central atom that has 2 to
	Predict the molecular geometries around a central atom that has 2 to 6 elec
	Predict the effect of a nonbonding pair of electrons on bond angle
Molecular Polarity	
	Using molecular geometry and bond polarity, predict whether a molecule is
Valence Bond Theory	
	Explain the molecular geometry in terms of pi and sigma bonds
	Identify cis vs. trans double bonds in molecules
	If given a molecule, predict what the hybridization around each central aton
Molecular Orbital Theory	
	Draw a molecular orbital diagram to predict bond order
	Draw a molecular orbital diagram to predict magnetism

Exention Connections

Topic	Detail
Tro Chapter 12 Intermolecular Forces	**Bolded topics are essential for assessment**
	identify and define the 4 types of IMFs
	invoke Coulomb's Law to explain IMFs
	use structure to rank substances by the strength of their IMFs
	use structure to rank substances by boiling points
Up vote from Bio	explain the role of IMFs in double-stranded DNA
	invoke IMFs to explain surface tension, viscosity, cohesion, adhesio
	invoke IMFs to explain vapor pressure, vaporization
	use structure to rank substances by vapor pressure, viscosity, surfac
	define phase changes in terms of IMFs
Thermodynamics of Phase Changes	
	write and manipulate a phase change reaction and the correspondin
	invoke dynamic equilibrium for vapor pressure in a closed container
	use ΔHvap in calculations with mass, moles and energy
	interpret vaporization curve (pressure vs. temp)
	use Claussius-Clapeyron eqn
	define critical temp and critical pressure
hopefully will be covered with entl	calculate a heating curve for water
	calculate a heating curve for any substance
	calculate heat transfer involving a phase change
Phase Diagrams	
	Identify melting, vaporization, sublimation curves on a phase diagra
	identify the triple point and critical point on a phase diagram
	identify temperatures and pressures of melting, boiling, sublimatior
	determine whether the solid or liquid is more dense from a phase di
	recognize that there can be multiple distinct solid phases with differ
Water!	
Up vote from Bio	enumerate the notable/unique properties of water
Up vote from Bio	explain how the unique properties of water sustain life and Earth's c
Tro Chapter 13 Structure of Solids	
	recognize that there can be multiple distinct solid phases with differ
	explain (in general terms) how x-ray diffraction is used to determine
	recognize that there are multiple geometric unit cells for crystalline
	recognize that the unit cell geometry is apparant from the macro str
	recognize that a glass has a disordered structure similar to a liquid
	identify the key interactions (IMFs or bonds) in different solid substa
Materials	
	identify allotropes of carbon
	identify silicates
	identify ceramics, cement, and glasses
	explain how band gaps affect conduction (conductor, semiconductor,
orgo?	define and identify polymers, monomers, dimers,
Tro Chapter 14	

Solutions	
	identify types of solutions
	invoke IMFs to explain solubility
	Define and identify examples of colloid and colloidal dispersions
	define the Tyndall effect
Thermodynamics of Solubility	
	Define ΔHsoln in terms of ΔHsolute, ΔHsolvent, ΔHmix
	Define ΔHsolute in terms of ΔHlattice
	Define ΔHhydration in terms of ΔHsolvent and ΔHmix
	Predict spontaneity of solution using ΔH and ΔS values
Concentration	
	calculate and introconvert between different units of concentration
	molarity
	molality
	mole fraction
	mole %
	parts by mass (%, ppm, ppb)
	parts by volume (%, ppm, ppb)
Colligative Properties	
	Explain colligative properties invoking IMFs
	Calculate vapor pressure lowering using Raoult's Law
	Explain deviations from Raoult's Law invoking IMFs
	Calculate freezing point depression and boiling point elevation
Up vote from Bio	Define osmotic pressure
Up vote from Bio	Calculate osmotic pressure
Up vote from Bio	Relate osmotic pressure to cell health and reverse osmosis
	use van't Hoff factor for strong electrolytes
Tro Chapter 26 Properties of Transition metals	
after VESPR	**Write the electron configuration of a transition metal ion**
after VESPR	**Recognize the diversity of oxidations states (and colors) of transitio**
after VESPR	**Define ligand, coordination compounds, transition metal complex, c**
after VESPR	**Define and identify primary valence, secondary valence, coordinatic**
late in IMFs	**Describe the nature of a metal-ligand bond**
after VESPR	**Define and identify ligand denticity and chelating agents**
after VESPR	**Identify the geometry complex ions**
after VESPR	**Distinguish between different types of isomers**
Bonding in Coordination Compounds	
	Explain crystal field theory (basics) for octahedral complexes
	Fill electrons in weak and strong field octahderal complexes
	Fill electrons in tetrahedral and square planar complexes (if splitting
	Relate crystal field theory to para/diamagnetism and the color of oc
	Applications of color of transition metal complexes (art, bio)
Tro Chapter 16 Equilibrium Basics	
	Explain dynamic equilibrium (depth depends on Kinetics coverage)
	Define K in terms of the law of mass action (equilibrium expression
	Explain balance of equilibrium from K value

Perform "Chemical Equation Math" with Ks
Write equilibrium expressions with conc. And pressures
Write equilibrium expressions for reactions with solids and/or liquid

Equilibrium Calculations

Calculate K from conc. or pressure
Calculate conc. Or pressure from K
Calculate Q
Compare Q and K to reaction direction
Use ICE table to calculate equilibrium conc.
Justify, employ, and evaluate simplifying assumptions in ICE tables
Relate Le Chatlier's Principle to changes in equilibria (conc., temp, v

Tro Chapter 19 (part 2)
Thermodynamics and Equilibrium

Relate ΔGrxn and ΔGrxn^o to Q and K
Explain standard and non-Standard states
Calculate K at different T using ΔG, ΔH and ΔS

Tro Chapter 17
What are Acids and Bases

Define and Identify Acids and Bases (Arrhenius)
Define and Identify Acids and Bases (Bronstead-Lowry)
Define and Identify Lewis Acids and Bases
Write acid dissociation, base hydrolysis reactions
Identify conjugate acid/base pairs
Define strong vs. weak acids and bases
Memorize strong acids and bases
Memorize common weak acids and bases
Classify acids as binary acids or oxyacids and rank them by strength

Strength of Acids and Bases

Write Ka, Kb, Kw in terms of equilibrium expressions and correspon
Convert Ka, Kb, Kw
Compare acid/base strength by Ka and Kb
Interconvert between Ka, Kb, Kw and pKa, pKb, pKw
Define pH and pOH
Determine whether a solution is acidic or basic from pH and/or pOH

Acids and Bases Calculations

Calculate the pH(pOH) of strong acid or base solutions
Calculate the pH of a weak acid solution
Calculate the pH of a weak base solution
Calculate % ionization
Classify salts as acidic, basic, neutral, or "its complicated"
Calculate the pH of a conjugate weak acid/base salt solution
Calculate pH of mixtures of acids (strong and weak)
Calculate pH and species concentrations of polyprotic acid solutions

Tro Chapter 18 - Aqueous Ionic Equilibria
Buffers

Define and identify a buffer
Calculate the pH of a buffer solution
Use the Henderson-Hasselbach equation

	Determine the recipe for a buffer solution at a particular pH, from w
	Determine the recipe for a buffer solution at a particular pH, from w
	Calculate pH change in buffer upon addition of strong acid or base (I
	Define and evaluate buffer capacity.
	Identify and calculate effective buffer pH range.
Titrations	
	Define acid-base titration, indicator, equivilance point, end point, tit
lab	**Describe the experimental setup and procedure of a titration**
lab	**(Perform a titration)**
	Calculate the volume of titrant needed to reach the end point of an /
	Calculate the pH after various volumes of titrant added. (WA+SB, W
	Plot data from a titration.
	Interpret a titration plot (identify end point, buffer region, equivalen
	Choose an appropriate indicator for a given titration.
Solubility/Precipitation	
	Write a solubility (dissolution) reaction equation
	Write a solubility product (equilibrium) expression (Ksp = ...)
Teach mass solubility instead	Define and calculate molar solubility
	Calculate equilibrium concentrations for a solubility reaction starting
	Calculate equilibrium concentrations for a solubility reaction with co
	Compare solubility of two substances.
	Use Q to predict precipitation of a single insoluble solid.
	Use Q to predict precipitation of a between two insoluble solids.
	Determine solubility using qualitative methods.
Complex Ion Equilibria	
	Define and write a Kf equilibrium expression (with corresponding rea
	Calculate equilibrium concentrations for a complex ion formation rea
	Qualitatively explain effect of complex ion equilibria on solubility.
	Qualitatively explain the solubility of amphoteric metal hydroxides.
Tro Chapter 20 - Electrochemistry Oxidation-Reduction Reactions	
	Identify Oxidation States
	Identify oxidation and reduction half reactions
	Balance redox reactions (acid conditions)
	Balance redox reactions (basic conditions)
Galvanic Cells	
	Define electrical current, potential, electrochemical cell, galvanic ce
	Define half-cell, electrodes, salt bridge, cathode, anode
	Identify and use units of amperes(A), volts(V)
	Define electromotive force/cell potential (including standard emf/p
	Interpret and write electrochemical cell line notation
	Identify, describe a standard hydrogen electrode and its relationship
	Use a standard electrode reduction potential table to find values and
	Calculate the E° of an electrochemical cell, relate to spontaneity
	Predict whether a metal will dissolve in acid using standard reductio
	Calculate the relationship between E°cell to ΔG° and K
Cell Potentials and Concentration	
	Calculate Ecell under non-standard conditions.

	Calculate the relationship between Ecell, ΔG, and Q
	Set up and perform calculations for a concentration cell
	Explain the function of human nerve cells as concentration cells
Nate has giant batteries	Explain the function of batteries using electrochemistry terms and ca
Electrolysis	
	Describe the differences between a galvanic and an electrolytic cell
	Predict the products of electrolysis in a pure molten salt
	Predict the products of electrolysis in an aqueous salt solution
	Define overvoltage and its role in electrolysis
	Use the stoichiometry of electrolysis to calculate the extent of electr
	Explain corrosion and sacrificial anodes in terms of electrochemistry
Tro Chapter 15 - Kinetics Rates of Reaction	
	Express the rate of a reaction as the change in reactant or product
	Distinguish between average, instantaneous and initial rates.
	Use a table of data to calculte the average rate of reaction
(initial rates)	Use a plot of concentration over time to determine the average and
	Identify simple chemical/instrumental methods for measuring rates
	Define and identify a rate law, rate constant and reaction order.
	Distinguish between 0th, 1st, 2nd order reactions by their rate laws
	Distinguish between 0th, 1st, 2nd order reactions by their rate const
	Distinguish between 0th, 1st, 2nd order reactions by plots of concen
	Distinguish between 0th, 1st, 2nd order reactions by plots of rate vs
	Determine the order of a reaction and reactant from a table of initia
Integrated Rate Laws	
	Explain the utility of an integrated rate law
	Identify 0th, 1st and 2nd order integrated rate laws
	Identify 0th, 1st or 2nd order reactions from plot conc., ln(conc.), or :
	Relate the equation of a line to linearized integrated rate law plots i
	Use an integrated rate law to calculate the conc. at time t from rate
	Calculate the t1/2 from 0th, 1st, and 2nd order reactions
Molecular View of Reaction Kinetics	
	Interpret and draw the energy vs. reaction progress diagram.
	Identify and explain activation energy, frequency factor, activated c
	Explain the exponential factor a fraction of molecules with sufficien
	Use the Arrhenius equation to calculate rate constants as a function
	Use the collision model to describe activation energy (orientation, co
	Define an elementary step, reaction intermediate, molecularity.
	Use "reaction mechanism" appropriately to describe the moleculari
	Identify a rate-determining step given a reaction mechanism and/or
	Determine the rate law for an overall reaction given a mechanism
	Define a catalyis, homogeneous catalyst, heterogenous catalysist
	Explain catalysis in terms of a reaction energy diagram.
Up vote from Bio	Give examples of catalysts from nature, biology, industry, consumer
Tro Chapter 21 - Nuclear Chemistry Radioactivity	
ealier in atoms first? pay attention	**Define radioactivity, radioactive, nuclide, ionizing power, penetratin**
	Write symbol notation for isotopes

	Define and write the symbol for alpha, beta(electron), proton, neutr
	Balance nuclear equations
	Define and identify parent and daughter nuclides
	Write eqn for alpha, beta, and gamma decay, electron capture, posi
	Predict stability of an isotope and type of reaction from the valley of
	define strong force
	Identify magic numbers of protons and neutrons
Up vote from Bio	Explain methods of radioactivity detection (dosimeters, Geiger coun
Nuclear reaction kinetics	
	Know that all radioactive decay is 1st order and apply 1st order kine
	Perfrom calculations for half-life of radioactive decay
	Explain and apply radiometric dating data (various isotopes)
Nuclear Energy	
	Describe and identify nuclear fission and fusion.
	Discuss the relevance of the Manhattan Project, to the US, to the loc
	Explain the operation of a nuclear power reactor.
	Evaluate the problems of nuclear power.
	Calculate the mass defect and nuclear binding energy
	Explain the nuclear binding energy curve
	Explain the role of nuclear fusion in stars.
	Explain the significance of a fusion reactor.
	Define transmutation
	Explain the operation of a linear reactor and a cyclotron.
	Explain the role of radiation on impacts to living things and in medic
Tro Chapter 22 - Organic Naming	
	Define and identify alkanes, alkenes, alkynes
in structures	**Draw the Lewis Dot structure for simple organic molecules**
	Identify cyclic hydrocarbons.
in structures	**Draw simplified organic structures.**
	Name 1-10 carbon alkane chains
in IMFs	**Relate hydrocarbon chain length to melting/boiling points**
	Idenitfy stereo and geometric isomers.
	Identify resonance and aromaticity in hydrocarbons.
amines and carboxylic acids	**Identify simple functional groups.**

Appendix 2. Draft Calendar for new CHEM 125-126 Curriculum

Draft Course Calendars

Date
Main Topic(s)
penStax Sectio

CHEM 125/135

Fall 2022	LAB	SUN	MON	TUES	WED	THURS	FRI	SAT
WEEK 1	**Safety Training & Safety Quiz #1 Online in Canvas**			8/30/22	8/31 Intro	9/1	9/2 Matter: phase, classify, properties 1.2-1.3	9/3
WEEK 2	**Check-in & LAB 1: Sucrose Density Gradient**	9/4	9/5 Measurements & matter 1.4-1.5	9/6	9/7 Accuracy & precision 1.5-1.6	9/8	9/9 Atomic theory 2.1-2.2	9/10
WEEK 3	**LAB 2: Microchemical Testing (of Museum Objects)**	9/11	9/12 Atomic structure, symbolism, formulas (molecular & empirical) 2.3-2.4	9/13	9/14 The mole 2.4	9/15	9/16 Electromagnetic energy: waves, blackbody radiation & UV catastrophe 3.1	9/17
WEEK 4	**LAB 3: Spectroscopy & Chromatography (Forensic Analysis)**	9/18	9/19 Photoelectric Effect, line spectra, Bohr Model 3.1-3.2	9/20	9/21 Development of Quantum Theory 3.3	9/22	9/23 *Pauli Exclusion Principle, electronic structure of atoms* 3.3-3.4	9/24
WEEK 5	**No Lab**	9/25	9/26 Periodic variation in element properties 3.5-3.6	9/27	9/28 Review Session or Exam 1 CH 1, 2, & 3.1-3.2	9/29 Exam 1?	9/30 Molecular & ionic compounds; ionic bonding 3.7, 4.1	10/1
WEEK 6	***Online Safety Assignment (read) & Quiz #2 in Canvas***	10/2	10/3 Covalent bonding, ionic nomenclature 4.2-4.3	10/4	10/5 Molecular compound nomenclature; Lewis theory 4.3-4.4	10/6 No classe Fall Break	10/7	10/8
WEEK 7	**Lab 4: Molecular Structures (add report to submit?)**	10/9	10/10 Exceptions to octet rule, formal charge, resonance, VSEPR 4.4-4.6	10/11	10/12 Predicting Molecular structures, polarity & dipole moment 4.6	10/13	10/14 Valence Bond Theory, hybrid atomic orbitals 5.1-5.2	10/15
WEEK 8	**Lab 5: Reactions of an Alkaline Earth**	10/16	10/17 *Hybridization & multiple bonds* 5.2-5.3	10/18	10/19 Formula mass, determining chemical formulas 6.1-6.2	10/20	10/21 Molarity & other units for solution concentration 6.3-6.4	10/22
WEEK 9	**Lab 6: Standardization of NaOH**	10/23	10/24 Writing & balancing equations, ppt rxns & solubility 7.1-7.2	10/25	10/26 Review Session or Exam 2 CH 3.3-3.7, 4, 5, 6	10/27 Exam 2?	10/28 Acid-base rxns, redox rxns 7.2	10/29
WEEK 10	**Lab 7: Citrus Lab (Quality Control & Data Analysis)**	10/30	10/31 Yield & Limiting Reactants 7.3-7.4	11/1	11/2 Quantitative Chemical Analysis 7.5	11/3	11/4 Gas Pressure 8.1	11/5
WEEK 11	**LAB 8: The Ideal Gas Law in the Real World**	11/6	11/7 Gas Laws; P, V, n, T to the ideal gas law 8.2	11/8	11/9 Gas reactions & stoichiometry 8.3	11/10	11/11 *Effusion, diffusion & KMT* 8.4	11/12
WEEK 12	**LAB 9: Limiting Reactant (Sidewalk Chalk)**	11/13	11/14 Intermolecular forces 10.1	11/15	11/16 Properties of liquids; phase transitions & diagrams 10.2, 10.4	11/17	11/18 Solid state of matter 10.5	11/19
THANKSGIVING	***No Lab***	11/20	11/21	11/22	11/23 THANKSGIVING BREAK	11/24	11/25	11/26
WEEK 13	**LAB 10: Freezing-Point Depression (Candle Wax Lab)**	11/27	11/28 Dissolution process, electrolytes, solubility 11.1-11.3	11/29	11/30 Solutions 11.3	12/1	12/2 Mole fraction & molality; colligative properties 11.4	12/3
WEEK 14	**LAB checkout & final exam**	12/4	12/5 Freezing pt depression, solution phase diagram, osmotic pressure, electrolytes 11.4	12/6	12/7 **Review Session or Exam 3** **CH 7, 8, 10, 11**	12/8 Exam 3?	12/9 *Semester Review*	12/10
FINALS WEEK		12/11	12/12	12/13	12/14 **Final Exam (cumulative & multiple choice)**	12/15	12/16	12/17

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skips Chapter 18 (representative metals, metalloids, and nonmetals) and 21 (organic)

Spring 2023	LAB	SUN	MON	TUES	WED	THURS	FRI	SAT
WEEK 1	**Safety Training & Safety Quiz #1 Online in Canvas**		NO CLASSES [MLK DAY]	1/17/23	1/18 Energy basics 9.1	1/19	1/20 Calorimetry 9.2	1/21
WEEK 2	**Check-in & Lab 11: Synthesis of Alum (percent yield)**	1/22	1/23 Phase transitions 10.3	1/24	1/25 Enthalpy, enthalpy of combustion, enthalpy of formation, Hess's law 9.3	1/26	1/27 First Law of Thermodynamics; strength of ionic & covalent bonds 9.3-9.4	1/28
WEEK 3	**Lab 12: Heat Transfer in the Real World (Coffee Cup Calorimetry)**	1/29	1/30 Spontaneity, entropy 12.1-12.2	1/31	2/1 2nd & 3rd Laws of Thermodynamics ; free energy 12.3-12.4	2/2	2/3 WS #1 Thermodynamics	2/4
WEEK 4	**Lab 13: Fresco**	2/5	2/6 Chemical equilibria; K 13.1-13.2	2/7	2/8 Le Chatelier's Principle; calculations with/for K 13.3-13.4	2/9	2/10 Calculations from initial conditions; temp dependence of equilibria 13.4	2/11
WEEK 5	***No Lab***	2/12	2/13 Bronsted-lowry acids/bases; molecular structure & acid/base strength 14.1, 14.3	2/14	2/15 Review Session or Exam 1 CH 9, 10.3, 12, 13	2/16 Exam 1?	2/17 Ka & Kb; conjugate acid-base pairs; pH & pOH 14.3, 14.2	2/18
WEEK 6	***Canvas Exam: Lab Quiz 1***	2/19	2/20 No Class President's Day	2/21	2/22 Acid/base equilibrium calculations 14.3	2/23 NO Class P&P	2/24 Hydrolysis of salts; polyprotic acids 14.4-14.5	2/25
WEEK 7	**Lab 14: Beer's Law (G3 on silk; shibori)**	2/26	2/27 WS #2 Acid/base Molecular Structure & Equilibria Calculations	2/28	3/1 Buffers 14.6	3/2	3/3 WS #3 Calculating pH of buffer solution	3/4
WEEK 8	**Lab 15: Acid-base Rxn of Soapmaking & buffers**	3/5 Acid-base titrations 14.7	3/6	3/7 WS #4 Calculating pH changes during a titration	3/8	3/9 Exam 2? CH 14	3/10	3/11
SPRING BREAK	***No Lab***	3/12	3/13	3/14	3/15 SPRING BREAK	3/16	3/17	3/18
SPRING BREAK	***No Lab***	3/19	3/20	3/21	3/22 SPRING BREAK	3/23	3/24	3/25
WEEK 9	**Lab 16: Ion exchange: removing heavy metal contaminants**	3/26	3/27 Precipitation & dissolution 15.1	3/28	3/29 Lewis acids & bases; Transition metal compounds, coordination compounds 15.2, 19.1-19.2	3/30	3/31 Structures/ isomerism/ coordination of complexes 19.2	4/1
WEEK 10	**Lab 17: Photochemistry**	4/2	4/3 Review redox, galvanic cells, electrode/cell potentials 16.1-16.3	4/4	4/5 *Potentials, free energy & equilibrium, batteries & fuel cells* 16.3-16.5	4/6	4/7 Corrosion & electrolysis 16.6-16.7	4/8
WEEK 11	***No Lab***	4/9	4/10 WS #5 Electrochemistry	4/11 No classes WUC	4/12 Chemical rxns rates, factors of rxn rates 17.1-17.2	4/13	4/14 Exam 3? CH 15, 19, 16	4/15
WEEK 12	**LAB 18: Electrochemistry in the Arts (Anodizing Aluminum & Etching Brass)**	4/16	4/17 Rate Laws, intgrated 1st order rxn 17.3-17.4	4/18	4/19 Integrated 2nd/0 order rxn; 1/2 life; collision theory 17.4-17.5	4/20	4/21 Ea; Arrhenius equation, rxn mechanisms 17.5-17.6	4/22
WEEK 13	**LAB 19: Kinetics of Bleach (Decolorizing Dyes)**	4/23	4/24 Catalysis; Nuclear structure, stability & equations 17.7, 20.1-20.2	4/25	4/26 WS #6 Kinetics	4/27	4/28 Radioactive Decay 20.3	4/29
WEEK 14	**LAB FINAL EXAM & Checkout**	4/30	5/1 Transmutation & nuclear energy 20.4	5/2	5/3 *Review Session Exam 4*	5/4	5/5 **Exam 4?** CH 17, 20	5/6
WEEK 15 & FINALS	***No Lab***	5/7	5/8 *WS #7 Intro to organic chem (while reviewing Lewis theory &*	5/9 *Reading Days*	5/10	5/11 **Final Exams**	5/12	5/13
FINALS WEEK		5/14	5/15 **Final Exam**	5/16	5/17	5/18	5/19	5/20