# Chemistry Topics for UIL

Dr. Brian Anderson
2024–2025

Here are the topic areas that will be covered in the chemistry section of the UIL Science Contest, along with a brief description of what makes up each topic area. Many problems fall into more than one topic area (combining pH with solubility, for example). There will be at least one question from each topic area on each exam.

1. Fundamentals
2. Stoichiometry
3. Atomic Theory
4. Chemical Bonding and Structure
5. Gases
6. Liquids and Solids
7. Thermodynamics
8. Physical Equilibria
9. Chemical Equilibria
10. Acids and Bases
11. Solubility Equilibria
12. Electrochemistry
13. Chemical Kinetics

At the Invitational level the problems are fairly straightforward and the calculational problems are typically one or two steps. As students progress through the contest, problems become increasingly complex, involving multi-step calculations, and sometimes solving a single problem will require using multiple different equations. All exams will be a mix of conceptual (non-calculational) problems and quantitative (calculational) problems. Conceptual does not mean easy!

## 1 - Fundamentals

Measurements, significant digits, fundamental SI units, metric prefixes, unit conversions, classification of matter, the mole, concentration terms, isotopes, accuracy vs precision, extensive vs intensive properties, physical vs chemical properties.

## 2 - Stoichiometry

*Compositional stoichiometry*: chemical formulas, empirical formula, formula units, molar mass, percent composition, nomenclature, ionic compounds, covalent compounds, first 10 hydrocarbons (alkanes), grams to moles and vice versa.

*Reaction stoichiometry*: types of chemical reactions, balancing reactions, predicting amounts of products, limiting reactant, percent yield. Tie-ins to other topics include things like calculating moles from pressure/volume of gases, calculating concentrations of solutions in percent by mass, molarity, molality, ppm, ppb, and mole fraction.

# Chemistry Topics for UIL

2020–2021

## 3 - Atomic Theory

Parts of the atom. Relative size of atoms. Electromagnetic radiation, frequency, wavelength, energy of one or more photons, Planck's constant. Photoelectric effect, work function of a metal. Quantum theory, line-spectra (emission and absorption), energy levels within the atom (Rydberg equation). Wave-particle duality and the deBroglie equation. Quantum numbers and the rules for each of them. The relative size and shapes of the atomic orbitals of hydrogen. Aufbau principle, Hund's rule, Pauli exclusion principle. Writing electron configurations for atoms and monatomic ions. Periodic Table: names of groups 1A, 2A, 7A, and 8A (or 1, 2, 17, and 18), trends of physical and chemical properties of the elements. Ionization energy, electron affinity, electronegativity, atomic radii, ionic radii, metallic character.

## 4 - Chemical Bonding and Structure

Octet rule, Lewis structures (dot and line), bond order, incomplete octets, expanded octets. VSEPR Theory and electronic and molecular geometries of molecules and ions (shapes, names, angles). Valence Bond (VB) or Localized Electron (LE) theory of bonding: hybrid orbitals and their shapes and angles. Sigma and pi bonding. Molecular orbital (MO) theory. Bonding orbitals and anti-bonding orbitals. Bond order in MO theory. Molecular polarity, dipole moment. Interpreting organic line structures.

## 5 - Gases

Gas laws: Boyle's, Charles', Avogadro. Combined gas law, the Ideal Gas Law. Gas mixtures: Dalton's Law of Partial Pressures. Gas behavior: kinetic molecular theory. Root-mean-square velocity of a gas particle ($v_{rms}$). Diffusion and effusion of gases. Real gas behavior and its deviation from ideal behavior, the van der Waals equation for real gases.

## 6 - Liquids and Solids

The condensed states – intermolecular forces (IMFs): dipole-dipole, H-bonding, and dispersion forces. Physical property trends and their relation to IMFs.
Properties: melting point, boiling point, viscosity, surface tension, and vapor pressure. Lattice energies of solids (crystals).

## 7 - Thermodynamics

First Law: heat and work, internal energy, enthalpy. Calorimetry, thermochemistry, heats of reaction, heats of combustion, bond energies, Hess's Law. Endothermic vs exothermic reactions. Work of an expanding gas. Second Law: spontaneity and entropy. Defining entropy. Gibb's Free Energy and spontaneous changes. Equilibrium and free energy.

# Chemistry Topics for UIL

2020–2021

## 8 - Physical Equilibria

Enthalpies (heats) of transition (fusion, vaporization, sublimation, condensation,…). Entropy of these changes. Free energy change during these transitions. Phase diagrams. Colligative properties: vapor pressure lowering (Raoult's Law), freezing point depression, boiling point elevation, and osmotic pressure. The van't Hoft factor (*i*) – how it relates to strong electrolytes and weak electrolytes.

## 9 - Chemical Equilibria

The equilibrium constant, $K$ . Using $K$. $K_c$ and $K_p$. The form of $K_c$ . The reaction quotient, $Q$ . LeChatlier's Principle – predicting rxn direction of reactions under a set of conditions, stressing a reaction and predicting change. $\Delta G$ vs $K$ . Heterogeneous equilibria.

## 10 - Acids and Bases

Strong vs weak acids and bases. The definition and use of pH. Ionization constants for weak acids ($K_a$) and bases ($K_b$). Calculating pH. Buffer solutions: defining a buffer, common ion effect, calculating pH of a buffer solution, LeChatlier's Principle and buffers (response to acid or base additions). Titrations: calculating the pH during a titration (strong or weak acids and bases), pH at the equivalence point. Indicators: how they work, determining the color of an indicator and its use as an end point for titrations.

## 11 - Solubility Equilibria

Determining molar solubility from $K_{sp}$ and vice versa. Calculating concentrations of species for solubility equilibria. Common ion effect for solubility. Other conc terms like ppm. Fractional (or selective) precipitation calculations. Complex ion formation and the formation constant, $K_f$.

## 12 - Electrochemistry

Identifying redox reactions. Balancing redox reactions in acid or base solution. Definitions: anode, cathode, voltaic cell, electrolytic cell, electric current, electrolytic current, the faraday constant, oxidation, reduction, oxidizing agent, reducing agent, salt bridge, standard electrode potential ($E$), volts, standard cell potential, non-standard cell potential (use Nernst equation). Batteries: primary vs secondary vs fuel cells. Know the fundamentals of a lead storage battery (aka: a car battery).

# Chemistry Topics for UIL
2020–2021

## 13 - Chemical Kinetics
Defining the rate of a reaction. Units for reaction rates. Writing the reaction rate law equation. The specific rate constant and its units. Reaction order. Using tabulated data and using the Method of Initial Rates to determine the rate law for a reaction. The integrated rate laws for zero, first, and second order reactions. Half-life and its calculation. Reaction mechanisms: writing elementary steps for a reaction. Writing rate laws for elementary steps. Importance of the rate-limiting step. Potential energy diagrams for kinetic reactions (aka reaction profile) - interpreting activation energy of the forward and reverse reactions. Multi-step reaction schemes. Temperature effects on the rate (Arrhenius equation). How catalysts work and their effect on reaction rates - and how it changes the potential energy diagram.

# General Notes about the Chemistry Exams

I try to make the chemistry portion of the science contest feel like “the same test, only harder,” by using scalable problems. A student taking the Regional exam, for example, might see a familiar situation from the District exam, but this time the question being asked is more difficult to answer. Not all of the problems on each exam will be a more difficult version of a previous problem, but some of them always will be. Some problems will scale all the way from Invitational A to State. If a question on an early exam asks for the definition of a word, you will need to know what that word means on a later exam.

The chemistry exam is a mix of conceptual and quantitative problems. The conceptual problems are not always easier! As a student progresses through the contest, problems get more difficult and more demanding mathematically, and take longer to solve.

Some problems present a situation and ask a question, and the pathway for answering the question from the information provided may not be immediately apparent. These problems require some critical thinking.

Some problems may include information that is not necessary for solving the problem.

The data sheet for chemistry includes a 1) periodic table, 2) a collection of constants such as water data that is the same on all exams, and 3) a section of data that is specific to each exam. Parts 1 and 2 on the data sheet are the same for all exams and part 3 is different for every exam. Whenever possible I include any data necessary for solving the problem in the problem itself, but for space reasons I sometimes have to move the problem data to the data sheet.

Mathematical formulas and relationships (such as the gas laws, Nernst equation, etc.) are not provided on the data sheet. Students should memorize those.

## Some Textbook References and Online Resources for Chemistry

**The best resource is the one that makes the most sense to the student.**

**College Textbooks**
You don't need the newest edition, and I have seen perfectly good older editions of popular chemistry textbooks available for $10-15 at Half-Price Books in Austin and Dallas. You can also find problem-solving study guides there for around $10 or less.

I'm listing three chemistry textbooks here that I personally like along with my impressions of each one, but students should always use whatever resources make the most sense to them, whether in print or online. Contest questions are never taken directly from any textbook, so using one of these textbooks doesn't give a student an advantage over using any other resource.

*Chemistry: A Molecular Approach* by Nivaldo Tro
Currently the best-selling college chemistry textbook, well-written, well-organized, comprehensive, and very readable.

*Chemical Principles* by Steven Zumdahl (& Decoste on newer editions)
Previously used at UT-Austin. Not as easily readable as Tro, but the material is presented in an intuitive way (for me, at least). Note that Zumdahl has written something like seven different general chemistry textbooks for high school and college with slightly different titles and sometimes different authors (such as Zumdahl, Zumdahl & Zumdahl, Zumdahl & Decoste, Zumdahl, Zumdahl, & Decoste). I'm not familiar with all of his textbooks, but *Chemical Principles* is his mainstream, full-year college chemistry text. Various older editions of some of his textbooks are available online for free in pdf format. Just Google "Zumdahl chemistry free download" but be careful about downloading anything from sketchy websites.

*Chemistry* by Whitten, Davis & Peck & Stanley
Not as rigorous on some topics as Tro or Zumdahl, but in general a good choice for a high school student who is doing college level work.

**Free online Resources**
University of Texas at Austin (Department of Chemistry)
This is a bare-bones online textbook used by most general chemistry classes at UT – Austin. https://gchem.cm.utexas.edu

OpenStax College (Rice)
This is a free downloadable chemistry textbook in pdf format.
https://openstaxcollege.org/textbooks/chemistry