Integrating Scientific Inquiry Using the Historical Theory of Atomic Structure

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This curriculum unit is recommended for:
Chemistry/Atomic Structure/grades 10-12

Keywords: Chemistry, atomic structure, historical theory

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: Need a healthy digression to feed your students who think chemistry is the most difficult subject in high school? Try approaching the ultimate science course by drawing upon chemistry's connections to history, math, and English! This curriculum unit makes atomic structure come alive through color filled demonstrations and a student lab which study the color as excited electrons are produced in electrified gases and in burning metals in methanol and aqueous solutions. An exploration of what we know about atomic structure is rediscovered by following its development through the eyes of the scientists behind the theory. Literature about fireworks and a discussion of fluorescent lights, which are also gas discharge tubes, show relevancy of exciting electrons to emit color. The photon energy of emitted color is algebraically calculated utilizing Planck's constant, the wavelength from Bohr's model of the hydrogen atom and Balmer's electromagnetic spectra. The neutron-to-proton ratio of stable isotopes is graphed to better understand atomic stability. The conduction of electrolytes, utilizing a homemade light bulb apparatus, leads us to demonstrating how atoms become ions, salt nomenclature, and eventually to comparisons to other molecular bonding, and even to the key ideas about how acids and bases work.

I plan to teach this unit during the coming year to 180 students in Chemistry.

Integrating Scientific Inquiry Using the Historical Theory of Atomic Structure

Bonnie Bosworth

Rational

All too often in education we throw out the baby with the bathwater. In an effort to cover content, we sacrifice process.[1] The process of science is inquiry based, so to divorce what we know from whom and how we know it, loses our storyline. To teach atomic structure, leaving out the theorists and their discoveries, robs students of the opportunities to make real historical and practical connections.

Analyzing the historical development of the current atomic theory, rather than just analyzing the structure of atoms, isotopes, and ions, allows teachers to recognize and demonstrate the interconnectedness of content areas or other disciplines. As most chemistry students are juniors in high school, in addition to science, this unit also addresses course content standards for most eleventh graders: applying historical chronological thinking to interpret and create time lines; algebraically rearranging formulas to solve for a particular variable, graphing exponential functions; and reading an informational text to analyze a sequence of events and explain how individuals or ideas interact and develop.

Certain interconnections are obvious: chronological historical thinking and the analysis of a sequence of events in an informational text; creating algebraic equations that describe relationships and explaining how specific individuals or key ideas interact and develop over the course of a text. These connections solidify students' learning, and deepen their understanding of content by developing links appropriately aligned to other core subject areas.

The best way to address the teaching goals of having students explain observations, make inferences and predictions, and explain the relationship between evidence and explanation is to study the historical discoveries and perspectives that led to the development of our scientific knowledge about atomic structure.[2]

This curriculum unit not only analyzes the structure of atoms, isotopes, and ions, but also analyzes an atom in terms of the location of electrons, explaining the emission of electromagnetic radiation in spectral form in terms of the Bohr model.[3] It then explains the process of radioactive decay using nuclear equations and half-life. The duration of this unit is approximately two weeks long for classes meeting 90 minutes a day.

Presently, I have two classes, each with more than 30 honors chemistry students, and one class of less than 20 regular chemistry students. Most (78 percent) of the honors students are sophomores, the rest are eleventh graders, and one senior. My regular chemistry students are mostly juniors (65 percent), with the remaining students split equally between tenth graders and seniors. Most of my honors students are girls (59 percent), while my regular students are mostly boys (59 percent). More than half (54 percent) of my honors students are African American, while less than half (47 percent) of my regular chemistry students are black. Both levels of chemistry classes are approximately one third Caucasian or white students (33-35 percent). Eighteen percent of my regular students are Hispanic, two of these three are in the English as a Second Language program. My honors classes are only three percent Hispanic, and equal parts (five percent each) of Asian and Indian ethnicity. Two of my honors studentsand two of my regular chemistry students have Section 504 plans in place, one in each chemistry level with extended time and separate room testing accommodations for Attention Deficit Hyperactivity Disorder. I have one regular student with an Individualized Education Program with accommodations of extended time and multiple test sessions in the classroom environment for science.

Background

The history of chemistry is the second among three of Doris Kolb's *The Joys of Teaching Chemistry* in the preface of Shakhashiri's fourth volume of *Chemical Demonstrations*. Humor is the third joy, and chemical demonstrations first.

> Although many chemistry teachers feel they must ignore the background material in order to have enough time to discuss all the principles and theories, I think that the history is important. More than that, I think it is interesting, and I find that the students do too. The subject of atomic structure is much more impressive when you know something about how scientists were able to figure out what these things called atoms are like.[4]

Our story begins with Democritus' ideas about *atomos,* the tiny individual particles of matterthat he believed could not be created, destroyed, nor further divided paved the way forthe father of modern chemistry, Antoine Lavoisier to develop his Law of Conservation of Mass in 1789. In this atomic structure unit, students will balance nuclear equations representing reactions to satisfy the Law of Conservation of Mass by illustrating that mass is neither created, nor destroyed. This exercise will also extend to the conservation of mass number and atomic number.

The idea of the atom was rigorously defined by John Dalton's Atomic Theory (*New System of Chemical Philosophy*, 1808) in which he formally describes*compounds* and chemical *reactions*. My students' first unit is nomenclature and compositional stoichiometry, in which the classification of matter is included to define compounds in context of chemical reactions. Following this atomic structure unit is reactions and more stoichiometry. Dalton's description of a chemical reaction as atoms being separated, combined, or rearranged is still the easiest for students to grasp and comprehend.

The story of the fundamental structure of the atom began in 1898, Marie, the French version of her Polish name, Monya,[5]and Pierre Curie discovered the element radium, while working with the mineral uranite, known as pitchblende, an ore of uranium oxide. Marie named the process by which materials give off rays which darken photographic plates as *radioactivity*, and these rays and particles as *radiation*, and won the 1911 Nobel Prize in chemistry.

Ernest Rutherford identified alpha, beta, and gamma radiation when studying the effects of an electric field on the emissions from a radioactive source, and won the 1908 Nobel Prize in chemistry.In 1911, Rutherford discovered the *nucleus*, the positive, small, dense core of an atom (balancing the negative electrons to explain the neutral nature of matter) by bombarding gold foil with nuclear alpha particles. Rutherford clarified the "empty space" of Democritus' composition of matter to be within rather than surrounding the atoms. By 1920, Rutherford concluded that the nucleus contains positive *protons*, the charge of each being equal, but opposite to that of an electron.

In 1913, while working in Rutherford's laboratory, Neils Bohr proposed a quantum model to explain why elements' atomic emission spectra are discontinuous. His model correctly predicted the electromagnetic radiation frequencies of hydrogen's visible spectrum lines which had been measured by Johann Balmer in 1885. Bohr related the allowable energy states of hydrogen's electron to certain circular orbits. He assigned a quantum number to each orbit and calculated the radii. Bohr suggested that when hydrogen's electron is on the first energy level closest to the nucleus, the atom is in its *ground state*. The electron moves to a higher orbit or *excited state* when energy is added from outside the atom. The atom emits a photon corresponding to the difference between the energy levels associated with its orbits when the electron calms down to a lower state.

In 1905, Albert Einstein explained why blue light produces an electric current between two metal plates by proposing that the *photons* of blue light have sufficient energy to free electrons from the metal atoms. His *photoelectric effect* demonstrates the dual wave-particle nature of light.In 1921, Einstein received the Nobel Prize in Physics. In this unit, honors chemistry students will calculate the frequency (ν) and energy (E) of a photon after finding the wavelength (λ) from a Bohr model for the hydrogen atom.

Einstein fled Germany as a Jewish scientist in 1933 after Hitler was appointed chancellor. He made a public statement that, "As long as I have any choice in the matter, I shall live in a country where civil liberty, tolerance, and equality of all citizens before the law prevail."[6]Einstein became a professor at the Institute for Advanced Study in Princeton, New Jersey. I especially appreciate how Russ Humphreys, a particle physicist, applies Einstein's theory of general relativity to explain his white hole cosmology model's time-dilating event horizon.[7]

The American Physicist, Robert Millikan used J.J. Thompson's charge-to-mass ratio of an *electron* (cathode ray particle, first subatomic particle less than the lightest known atom, hydrogen) to calculate its mass (9.1×10^{-28} g, 1/1840 of a hydrogen atom) after accurately measuring its charge in 1909. In 1932, James Chadwick showed that the nucleus also contains neutral subatomic neutrons.

Teaching Strategies

Applying Kaplan and Gould's *Depth* and *Complexity* Matrix[8]to this unit helps define high-level content by showing how it challenges students to develop a more extensive understanding of chemistry, by deepening their thinking skills from the *Language of the Discipline* to the *Big Idea* (atomic structure); through chronological *Patterns*(atomic theory), *Details* (subatomic particles), and *Rules*. The dimension of complexity broadens from sequencing *Over Time* to relating *Across Disciplines.*

Big Ideas

Students will master these essential understandings:

<u>Atoms</u> of the same <u>element</u> do not necessarily have the same <u>mass</u>, due to differing numbers of *neutral* <u>neutrons</u> (<u>isotopes</u>). The number of <u>protons</u> determines the *identity* of an atom (neutral) or <u>ion</u> (*charged*, due to the number of *negative* <u>electrons</u> being *unequal* to the number of *positive* protons).

Each element has a unique discontinuous <u>atomic emission spectrum</u> or set of emitted <u>electromagnetic wave</u> frequencies (energy). Bohr's <u>quantum</u> (minimum amount of energy that can be lost or gained) model predicts the <u>frequency</u> (visible colored light) lines for <u>hydrogen</u>'s emission spectrum, by recognizing only certain allowable <u>energy levels</u> (*orbits*) for its one electron. Schrodinger's (wave) <u>quantum mechanical model</u> of an atom predicts a 3-D (three-dimensional) region around the nucleus (<u>atomic orbital</u>) which describes an electron's probable location. The atomic orbital is pictured as a *cloud* whose *density* at a given point is *proportional* to the *probability* of finding an electron there. Both models assign (principle) <u>quantum number</u> (*n*) to electron orbits or orbitals indicating increasing sizes and energies as electrons move further away from the nucleus.

Matter can only gain or lose energy in small specific amounts called <u>quanta</u>. An electron is considered to be in an <u>excited state</u> when it gains enough energy to move from its <u>ground state</u> (lowest allowable energy closest to the nucleus) to a higher energy level. When an electron moves to a lower energy level, it emits a <u>photon</u> (a particle of electromagnetic radiation with no mass that carries a specific quantum of energy) corresponding to the difference between the two levels. There is an <u>inverse relationship</u>between wavelength (λ) and frequency (v); $c = \lambda v$ ($c = 3.0 \times 10^8$ m/s, speed of light in a <u>vacuum</u>), and a <u>direct relationship</u> between energy (E) and frequency; $E = h v$ ($h = 6.626 \times 10^{-34}$ J x s, Planck's constant).

Mass and charge are *conserved* in a nuclear *reaction*. Transmutation occurs during the radioactive *decay* of *unstable* nuclei through the *emission* of positrons, alpha or beta *particles*, and by electron *capture*. Each radioisotope has its own characteristic half-life (*rate* of decay). Honors level chemistry is differentiated with this additional understanding; as one moves from low to high atomic number, the neutron-to-proton ratio for stable nuclei gradually increases from 1:1 to 1.5:1.

Language of the Discipline

Students will know the meanings of underlined three tier words (atoms, element, mass, neutrons, isotopes, protons, ion, electrons,atomic emission spectrum, electromagnetic wave,quantum, frequency, hydrogen, energy levels, quantum mechanical model, atomic orbital, quantum number,principle, angular, magnetic, spin,quanta, excited state,ground state,photon, inverse relationship, vacuum, direct relationship, radiation,ultraviolet, infrared, charge, nuclear, transmutation, radioactive, nuclei, positrons, alpha, beta, radioisotope, half-life, gamma, fission, fusion) and the italicized two tier words(*neutral, identity, charged, negative, unequal, positive,solutions, equation, spatial orientation, orbits, clouds, density, proportional, probability, transition, conserved, reaction, decay, unstable, emission, particles, rate*) within the above big ideas, and below within the language of the discipline.

In addition, students will know the following expressions: The mass number (A) is the number of protons plus the number of neutrons.The atomic number (Z) is the number of protons.

Students will also know:The four quantum numbers (*solutions* to Schrodinger's wave *equation*); *n* (principle – energy level and size), *l* (angular – sublevel and shape), *m* (magnetic – specific orbital/*spatial orientation*), *s* (spin – *direction*).

Essential knowledge is needed of the symbols for the nuclear particles; alpha ($_2{}^4He$), beta ($_{-1}{}^0e$), positron ($_1{}^0\beta$), and gamma (γ) radiation, and the distinction between fission and fusion.

Details and Rules

Students will demonstrate use of notation for writing isotopic symbols; ${}^Z_AX$ or X-A (X = chemical symbol), and use shorthand notation of particles involved in nuclear equations to balance and solve for unknowns. Honors chemistry students will also write a nuclear equation from a radioactive decay series.

Honors chemistry students will place quantum number addresses in their proper sequence according to the Aufbau and Pauli Exclusion principles and Hund's Rule, and list the four quantum numbers needed to describe certain designated electrons from an orbital diagram for the Electron Configuration unit to follow this one, so teaching forward provides another connection for learning.

Students will use the Bohr model for the hydrogen atom with an electromagnetic spectrum diagram to relate electron energy level *transition*, and wavelength of emitted visible light color or radiationtype; ultraviolet (UV), infrared(IR).

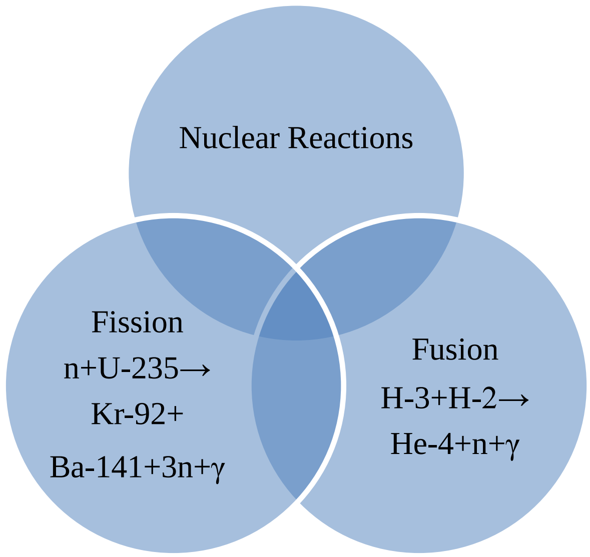
Across Disciplines

Students will calculate average atomic mass from relative abundance of actual isotopic mass. Honors level students will be differentiated by applying algebra to assign variables and solve for the relative percentages of two naturally occurring isotopes of an element, given its average atomic mass and the masses of each nuclide.

Honors chemistry students will calculate frequency (v) and energy (E) of the photon after finding the wavelength (λ) using the reference tables, $c = \lambda v$ (c = 3.0 x 10^8 m/s, speed of light in a vacuum), and $E = h v$ (h = 6.626 x 10^{-34} J x s, Planck's constant), differentiating instruction.

Students will calculate half-life problems, and compare and contrast fission and fusion using a Venn diagram.Radiometric dating ushers in a discussionabout agedetermination possiblybeing tainted by perspective. Certain presumptions are made from the uniformitarian view: a sample begins with 100 percent parent isotope; the sample is a closed system, no addition of the daughter nuclide; and of course, the rate of decay remains constant over time. The catastrophism viewpoint can also be considered in discussions.

The twin circle intersection within the Venn diagram could signify that both nuclear reactions (fission and fusion) yield energy and neutrons. Students will recognize reactors in a power plant to harness fission, and fusion in our Sun and other stars under conditions of extreme pressure and high temperatures.



Patterns/Over Time

Students will characterize subatomic particles (protons, electrons, and neutrons) by location and relative mass using a timeline table.

Subatomic Particles	**Charge**	**Relative Mass**	**Location**	**Nuclear Symbol**
Thomson late 1890s Electron	*Millikan 1909* negative	1/1840	*Bohr 1913* energy levels	$_{-1}^{0}\beta$ (beta)
Proton	*Rutherford 1920* positive	1 amu	*Rutherford 1911 (Au foil-αlpha)* nucleus	$_{1}^{1}p$
Neutron	*Chadwick 1932* neutral	1 amu	*Chadwick* nucleus	$_{0}^{1}n$

The honors level students will create and explain a graph illustrating radioactive decay, and use a band of stability graph of the number of protons vs. number of neutrons graph to determine whether an isotope is unstable. Students at the honors level will also associate electron capture or positron emission with nuclides falling below the belt of stability, beta emission with isotopes above the belt, and alpha decay with nuclides beyond the band of stability.

Demonstrations/Labs

Last, but certainly not least, is the overarching process by which this content is best presented—chemical demonstrations that show significance—priceless, lasting images. As in the second step of the parallel curriculum model protocol, demonstrations focus on relevant ideas, instead of facts, telling a story about the content by providing a structure for linking the main ideas in a rational order or related sequence.[9]

Activities

> Any effective activity is essentially a sense-making process, designed to help a student progress from a current point of understanding to a more complex level of understanding.[10]

Spectroscopy Demo(see Materials List)

Students will view line spectra through diffraction grating glasses emitted from argon, neon, hydrogen (H_2), nitrogen (N_2), oxygen (O_2), and mercury (Hg) low pressure gas discharge tubes with metal electrodes on either endplugged into a high voltage power supply. This demonstration will exemplify essential understandings of the *big idea* thateach element has a unique discontinuous atomic emission spectrum or set of emitted electromagnetic wave frequencies (energy).An electron is considered to be in an excited state when it gains enough energy to move from its ground state (lowest allowable energy closest to the nucleus) to a higher energy level. When an electron moves to a lower energy level, it emits a photon (a particle of electromagnetic radiation with no mass that carries a specific quantum of energy) corresponding to the difference between the two levels.

Students should realize that fluorescent lights are mercury and argon gas discharge tubes which emit energy in the ultraviolet range of the electromagnetic spectrum. The invisible UV rays are converted to visible light by coating these tubes with a fluorescent material. Turn off the power supply before changing the lamps. The classroom needs to be as dark as possible (close window blinds and doors). Students can use colored pencils to draw the spectra lines of each gas.

Colored Flames of Metal Ions Demo

> The emission of visible light from heated metal salts is responsible for the colors of fireworks. Heating metal salts in a flame also produces these colors and can be used to identify some metal ions.[11]

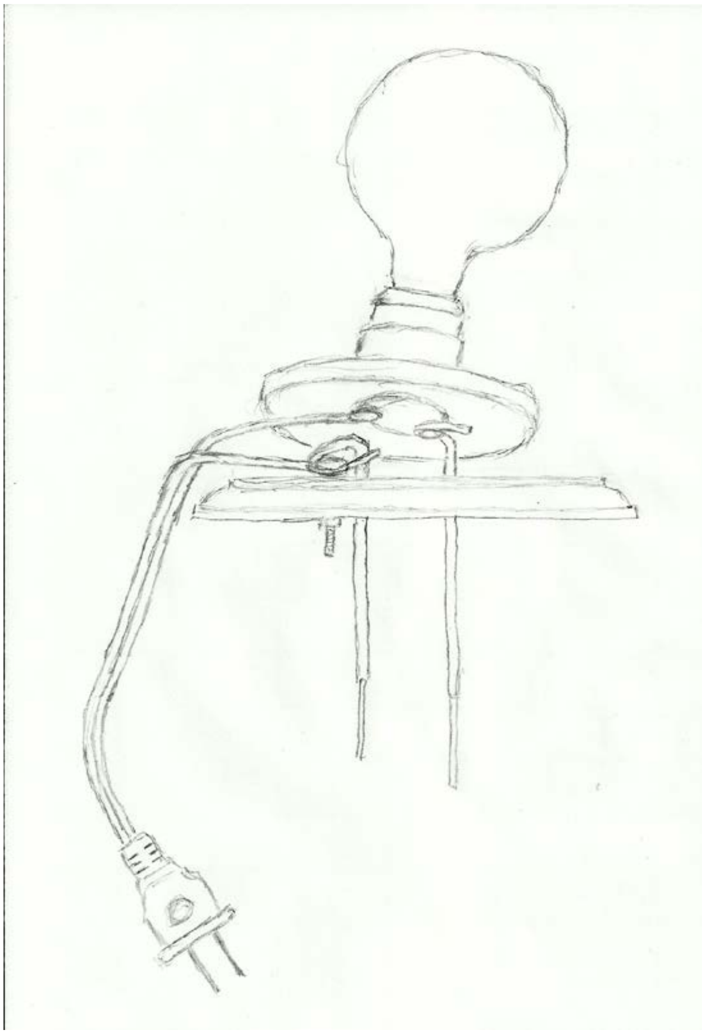
My students will read the article, Fireworks[12]while completing an anticipation guide. The author, Kathy De Antonis describes how the luminescent colors of fireworks are produced when the metal atom's electrons absorb heat energy to move from ground to an excited state, and then emit colored light when they go back to a lower energy level. There is also an interview with a pyrotechnic chemist included in that same issue on the last page of the article. This exercise touches upon the curriculum of practice parallel where students understand and use the discipline as a means of looking at and making sense of the world.[13]

Students will view the flame colors of excited metal ions; deep red lithium, yellow sodium, violet potassium, red-orange calcium, red strontium, yellow-green barium, and blue-green copper. 0.2 grams (g) of each of these seven metal chlorides (LiCl, NaCl, KCl, $CaCl_2$, $SrCl_2$, $BaCl_2$, and $CuCl_2$) will be combined with 20 milliliters (mL) of methanol (CH_3OH) in porcelain evaporating dishes. The dishes may be covered after preparation to prevent the evaporation of the alcohol. The room will be darkened after the liquid in the dishes on the display table is ignited. The solutions will be allowed to dry out before putting them in the trash.

Flame TestsStudents' Lab

Ni-chrome metal wireloop is dipped into salt solutions (after loop is cleansed in a beaker of dilute hydrochloric acid and held over the hottest part or cone tip of a Bunsen burner flame between and before each different solution) of lithium, sodium (Na), potassium (K), calcium, strontium (Sr), and barium and held over the Bunsen burner flame to observe and record the color. Safety goggles should be worn. This lab also solidifies the same big ideas as the *Spectroscopy* demonstration.

Conductivity of Solutions Demo

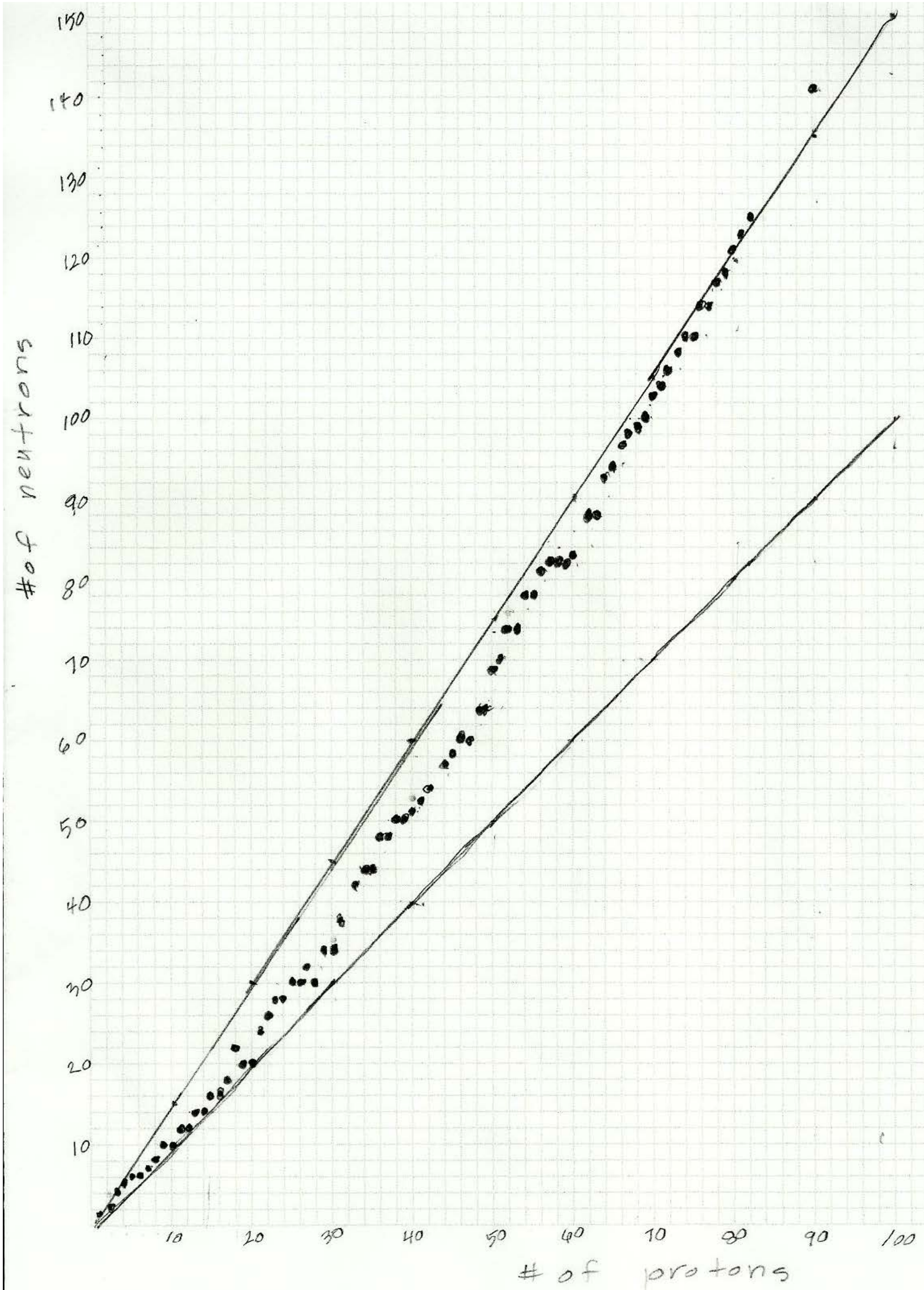


The above figure pictures the homemade conductivity light-bulb apparatus used in the following demonstration. The ability to conduct electricity will be demonstrated using electrodes being immersed in beakers of different solutions (metal salts or acids—electrolytes vs. nonmetal molecules). The copper (Cu) electrodes/wires are attached in circuit to a light bulb. When/if the bulb lights, electrons flowing in solution as negative anions are completing the circuit. This demonstration re-loops our first nomenclature/compositional stoichiometry unit to atomic structure, and also links to our last unit seven, acids and bases.

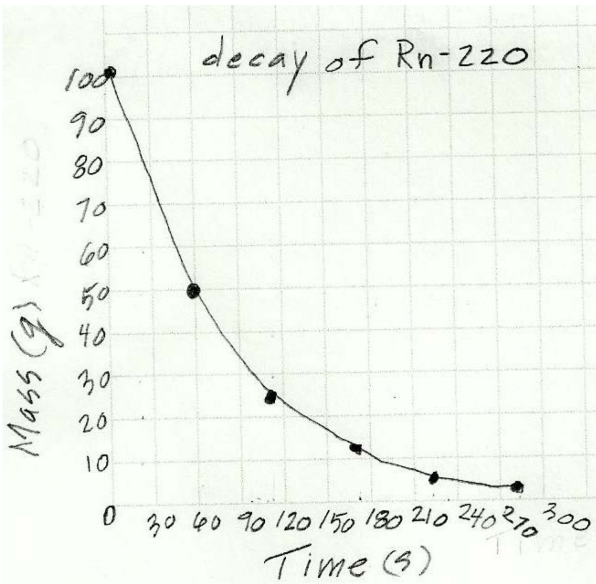
Graphing the Band of Stability

Students will create their own band of stability forstable isotopes of the first 82 elements and thorium. For most, they will use the average atomic mass on the periodic table rounded to the nearest whole number as a stable isotope for each. For the following list of thirteen elements, students will need to subtract one atomic mass unit from the nearest rounded whole number of the average atomic mass on the periodic table in order to find an actual stable isotope; nickel (Ni), copper (Cu), zinc (Zn), gallium (Ga), selenium (Se), bromine (Br), silver (Ag), antimony (Sb), neodymium (Nd), europium (Eu),rhenium (Re), iridium (Ir), and thorium (Th). Two of these first 82 elements have no stable isotopes and thus need to be excluded altogether; technetium and promethium, atomic numbers 43 and 61 respectively. Two further exceptions; indium-113 is its only stable isotope, and tellurium-126, is this atom's most massive isotope.[14]

Using an entire piece of graph paper, students will graph neutrons vs. protons. The y-axis should be scaled 0-150 for neutrons, and the x-axis, 0-100 for protons. Students will first need to make a table with four columns labeled; stable isotope, atomic number, protons, and neutrons. Students will plot points on the graph from their tables, and draw two lines; one representing a 1:1 ratio of neutrons to protons, and another representing a 1.5:1 ratio of neutrons to protons. These lines show that the most stable nuclei for atoms with a low atomic number (below 20) have a one neutron-to-one proton ratio, and the neutron-to-proton ration gradually increases to a maximum of 1.5:1 as atomic number increases. Students will compare their graph to this one:


150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
# of neutrons
10
20
30
40
50
60
70
80
90
100
# of protons

The purpose of this activity is to solidify the significance of the band of stability, and make predictions using this graphas to an isotope's stability more clearly understood. I also plan to have students graph their half-life problem solutions for practice in scaling exponential decay. The following is a sample of such a graph showing the decay of Radon-220 with a half-life of 56 seconds for a 100 gram sample:



Conclusion

This curriculum unit shifts the overarching theme of atomic *structure* to one of atomic structure's *relationship* to historical theory, applied math (the frequency and wavelength of electromagnetic energy), the colors of emitted light (excited electrons), the conductivity of ions in solution, and the stability of nuclei (based on atomic number, and the neutron-to-proton ratio). Students could approach chemistry from their interest in the history of subatomic discovery, the application of their mathematical skills, or the significance of awe-inspiring demonstrations to solidify their understanding of chemical concepts. I look forward to putting this entire unit to the test in the classroom to see whether comprehension and enthusiasm for an atom's structure flourishes because of my students' relationship to the content and process—the ultimate product!

Notes

[1]Atomic Theory can clearly be seen to have been removed from the North Carolina Chemistry Standards in the Department of Public Instruction's 2009 to 2004 Crosswalk document. The 2009 Essential Standards exclude the contributions of Democritus and Dalton, and the discoveries of Thomson, Millikan, Rutherford and Chadwick.

[2]The North Carolina Department of Public Instruction's Chemistry 2009 to 2004 Standards Crosswalk document also suggests that the missing 2004 Standard Course of Study Competency Goal 1, The learner will develop abilities necessary to do and understand scientific inquiry, should be integrated into classroom instructional design.

[3]These objectives are not typically included in this unit for the Professional Learning Community at our school, but usually are a part of an electron configuration/periodic trends unit to follow. Remarrying atomic theory to structure precludes leaving Bohr out of the mix. It also seems that presenting Bohr between subatomic and nuclear particles gives students time to digest the proton and electron, before being served the positron and beta particle.

[4]Shakhashiri, *Chemical Demonstrations: A Handbook for Teachers of Chemistry, Volume Four*, xv.

[5]Cobb, *Marie Curie*, 32.

[6]Wishinsky, *Albert Einstein*, 95.

[7]Faulkner, *Universe by Design: An Explanation of Cosmology and Creation*, 102.

[8]Capland and Gould, *The Flip Book, Too*: *More Quick and Easy Methods for Developing Differentiated Learning Experiences*, 9.

[9]Tomlinson, Kaplan, Purcell, Leppien, Burns and Strickland, *The Parallel Curriculum in the Classroom Book 1: Essays for Application Across the Content Areas*, 15.

[10]Tomlinson, *How to Differentiate Instruction In Mixed Ability Classrooms*, 79.

[11]Shakhashiri, *Chemical Demonstrations: A Handbook for Teachers of Chemistry, Volume 5*, 108.

[12]Antonis, Kathy De.Fireworks.*ChemMatters*, October 2010: http://www.acs.org/content/dam/acsorg/education/resources/highschool/chemmatters/archive/chemmatters-oct2010-free-compilation.pdf (accessed October 30, 2013).

[13]Tomlinson, Kaplan, Renzulli, Purcell, Leppien and Burns, *The Parallel Curriculum: A Design to Develop High Potential and Challenge High-Ability Learners*, 18.

[14]http://www.periodictable.com/Properties/A/StableIsotopes.html (accessed October 19, 2013). Up to date, curated data provided by Mathematica's Element Data function from Wolfram Research, Inc.

Appendix: Implementing Common Core Standards

2009 North Carolina Essential Standard Objective Chm.1.1, Analyze the structure of atoms and ions. This will be supplemented with the 2004 North Carolina Standard Course of Study Objective 2.01, Analyze the historical development of the current atomic theory.

North Carolina American History Essential Standard Clarifying Objective AH1.H.1.1, Use Chronological thinking (the application of one of the fourinterconnected dimensions of historical thinking) to interpret data presented in time lines and create time lines. Interpreting with mastery naturally follows creation.

North Carolina Algebra II Common Core StandardA.CED.4 Objective (Domain and Cluster—Create equations that describe numbers or relationships), rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange c (speed of light in a vacuum, 3×10^8 m/s) = ν to highlight wavelength λ, or rearrange Einstein's equation E_{photon} = h (Planck's constant, 6.626×10^{-34} J s) ν to highlight frequency ν.

North Carolina Algebra II Common Core Standard F.IF.7 Objective (Domain and Cluster—Interpreting Functions-Analyze functions using different representations), Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. e. Graph exponential and logarithmic functions. Honors chemistry students are assessed by their ability to graph exponential radioactive decay. Amount remaining = (Initial amount) $(1/2)^{t/T}$, where t = time, and T = half-life.

English III Common Core Standard 3 (under the Reading Informational Text Strand, and the Key Ideas and Details Cluster), analyze a complex set of ideas or sequence of eventsand explain how specific individuals, ideas, or events interact and develop over the course of the text. Students seem to especially struggle with comprehension when reading a scientific textbook.

Reading List for Students

Cobb, Vicki. *Marie Curie*. New York: DK Publishing, 2008. This photographic biography includes a chapter titled Science at the End of the 19th Century which pictures Count Rumford, John Dalton's elements, a Joseph Gay-Lussac trading card, and Demitri Mendeleev. There is a time line of events in Marie Curie's life, and she is pictured with Albert Einstein. Marie's daughter, Irene is pictured pointing to her mother's radium-scarred fingertips.

Dingle, Adrian.*The Periodic Table: Elements with Style!*New York: Scholastic, 2007. Elements are made interesting by their history and common use, for instance, James Chadwick bombarding beryllium with alpha particles to discover neutrons. The groups are arranged by descriptive chapters, such as the chalcogens, or ore formers.

Green, Dan. *Chemistry: Getting a Big Reaction!* New York: Scholastic, 2010. The introduction shows a caricature of Antoine Lavoisier. Classification, states, and properties of matter lead to basic safety, equipment, chemicals, and reactions defined, leading to earth resources, and life applications.

Green, Dan. *Physics: Why Matter Matters!* New York: Scholastic, 2009. An E(instein) = mc^2 caricature introduces the distinction between "old school" mass and weight. Speed and acceleration follow to forces, potential and kinetic energy, and even entrophy. Wave properties of the electromagnetic spectrum/"light crew", atomic and nuclear particles/"heavies" are also presented. Erwin Schrodinger ushers in electric "cuties".

Dingrando, L., Tallman, K., Hainen, N., Wistrom, C. *Chemistry: Matter and change.* Columbus, OH: Glencoe/McGraw-Hill, 2005. This is the textbook issued to students.

Wishinsky, Frieda. *Albert Einstein*. New York: DK Publishing, 2005. This account of Einstein's life shows how significant his contributions were not only to science, but also his amazing philosophy to a world threatened by Nazis.

Materials List(for Spectroscopy Demo from Fisher Scientific)

EISCO Spectrum Tube Power Supply S960205 ~$198
Spectrum Tube Hg S44000F ~$58
Spectrum Tubes ~$41/each; H_2 S43996F, Ne S43993F, N_2 S43997F, O_2S43998F
Diffraction Viewing Glasses 10 Assorted Color Frames S48814A ~$13

Bibliography

Eagle, Cassandra T. and Sloan, Jennifer. Marie Anne Paulze Lavoisier: The Mother of Modern Chemistry. *The Chemical Educator*, Vol. 3, No. 5. NY: Springer-Verlag, 1998. This article shows the intricate detail in one of Marie Anne's engravings and two of her drawings.

Kaplan, Sandra N., Gould, Bette. *The Flip Book, Too*: *More Quick and Easy Methods for Developing Differentiated Learning Experiences.* Las Vegas, NV: J Taylor Education, 2005. This can be purchased online as an electronic document.

Rogers, S. *Teaching for excellence: Essential concepts, strategies,techniques, and processes for ensuring performance excellence for all kids.*Conifer, CO: PEAK Learning Systems, 2012. I make much use of his learning support station in my classroom. He calls these a rescue station, a no writing zone where students can check their responses from the correct solutions and answers to problems and questions posted at a specific location.

Shakhashiri, B. Z. *Chemical Demonstrations: A handbook for teachers of Chemistry, Volume 4.* Madison, WI: University of Wisconsin Press, 1992. This volume contains clock reactions and electrochemistry (batteries, electrolytic cells, and plating) demonstrations.

Shakhashiri, B. Z. *Chemical Demonstrations: A handbook for teachers of Chemistry, Volume 5*. Madison, WI: University of Wisconsin Press, 2011. This volume contains demonstrations about color, light, vision, and perception. Shakhashiri list materials, and walks teachers through the preparation and presentation of different procedures for each demonstration. Hazards, disposal, a discussion, and references are also a part of each demonstration's instructions.

Tomlinson, Carol Ann. *How to Differentiate in Mixed-Ability Classrooms, 2nd Edition*. Alexandria, VA: ASDA, 2001. This book was the text for our district's differentiation academy. It illustrates how to plan lessons differentiated by readiness, interest, and learning profile. Tomlinson also shows how to differentiate content, process, and products.

Tomlinson, C. A., Kaplan, S. N., Renzulli, J. S., Purcell, J., Leppien, J., Burns, D. *The parallel curriculum: A design to develop high potential and challenge high ability learners.* Thousand Oaks, CA: Corwin Press, 2002. The four parallels within this curriculum model are; core, connections, practice, and identity.

Tomlinson, C. A., Kaplan, S. N., Purcell, J., Leppien, J., Burns, D., Strickland, C.

*The parallel curriculum in the classroom Books 1 and 2: Essays and Units forapplication across content areas.*Thousand Oaks, CA: Corwin Press, 2006.