Modification of Linguistic Instructional Strategies for Application in Chemistry: Progressing beyond Scientific Literacy to Chemical Fluency

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Modification of Linguistic Instructional Strategies for Application in Chemistry:
Progressing beyond Scientific Literacy to Chemical Fluency

by
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A thesis submitted to the Department of Education of The College at Brockport, State University of New York, in partial fulfillment of the requirements for the degree of Master of Science in Education December 5th, 2016
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Introduction

Centuries ago, when alchemists discovered bizarre substances that had never before been observed by human eyes, they recognized that the colloquial language of their times was wholly inadequate to describe their miraculous findings. To resolve this challenge, alchemists had no other option but to each develop their own chemical language, which can be seen in ancient notebooks and publications. Over time, the symbols and representations used by individual alchemists were amalgamated together, and eventually transformed into the scientific language that modern chemists use today.

With this historical perspective, it is quite reasonable to equate chemical terminology and representations with linguistic elements. In fact, chemistry educators have been supporting this notion for decades. In 1988, Markow published an editorial urging educators to begin their chemistry curricula with a unit based on learning the language of chemistry. He referred to chemistry students as foreign language learners and proposed that chemistry concepts can be taught with a similar methodology to foreign language laboratories (Markow, 1988). Markow (1988) further argued that chemistry teachers must make chemistry relevant to students, just as foreign language teachers provide relevance in bilingual education.

The idea of a chemical language has persisted in educational literature with sporadic revivals up to this current decade. Recently, Laszlo has developed and described a detailed, multi-layered language analogy that associates chemical representations to related linguistic elements (2013). Like Markow, Laszlo also has urged educators that chemistry should be taught
as a language by arguing that both linguistics and chemistry require the same problem solving process of heuristic cognition (2013).

This linguistic perspective of chemistry has also not been limited to educational research within the USA. In South Africa, Marais and Jordaan (2000) have proposed that chemical language requires specific focus within the classroom by demonstrating that chemical symbols within an assessment have adverse effects on performance. They have argued that the symbolic language used within chemistry requires high levels of abstraction and adds extra burden to chemistry students' already heavy cognitive loads (Marais & Jordaan, 2000). Marais and Jordaan (2000) have been one of the few authors who have suggested any strategies for chemical language support, however they have conceded that their proposed strategies are untested.

In Australia, a publication by Lim also has supported the need for chemistry to be taught as a language (2013). He has argued that despite sharing many vocabulary terms with English vernacular, chemistry is undoubtedly a unique language, because the common and scientific meaning of shared words are not equivalent (Lim, 2013). Lim (2013) has concluded that when shared words are not addressed in chemistry classrooms, such as the different definitions of acid, students struggle more with conceptual understanding. He even has warned that this confusion can even extend to communication issues with the general public (Lim, 2013). For example, many citizens reject and ignore the environmental crisis of ocean acidification, because their understanding of acid-base concepts is conflated between the undifferentiated chemical and common definitions of acid (Lim, 2013).

Though Lim (2013) does not explicitly mention the term, he has clearly highlighted the educational issue of scientific literacy as it relates to chemistry. Scientific literacy has been defined by the National Science Education Standards (1996) as "the knowledge and
understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity”. From this broad definition, Shwartz, Ben-Zvi, and Hofstein (2006b) have outlined the dimensions within scientific literacy: a scientifically literate person understands (1) the nature and methods of science, (2) basic science content knowledge, (3) the interaction of science and technology, (4) the impact of science and technology on society, and possesses (5) scientific communication skills, and (6) an ability to apply scientific knowledge and reasoning to everyday life.

Unfortunately, Shwartz, Ben-Zvi, and Hofstein (2005) have also uncovered a discordance between the definitions of scientific literacy that many teachers and scientists hold in a previous study. Partial agreement has been found between teachers and scientists, with the main areas of disagreement stemming from the prospective goal: "Teachers focus on the benefit to individual students, whereas scientists are concerned with benefits to society" (Shwartz, Ben-Zvi, & Hofstein, 2006a). Despite conflicting opinions on its definition, scientific literacy has remained as a primary goal in science education.

However, when cataloguing the most prevalent opinions regarding scientific literacy, it has become surprisingly clear that both scientists and chemistry teachers have ranked the language of chemistry as a low priority, with teachers placing slightly more importance on chemical language (Shwartz, Ben-Zvi, & Hofstein, 2006a). In the graphical supports under their analysis section, Shwartz, Ben-Zvi, and Hofstein (2006a) have demonstrated that within the outlined sections of chemical literacy, chemical language has been a small and little emphasized area of chemical literacy. Yet if chemical language has not been well-covered by literacy standards and definitions, where should it exist within educational philosophy? The answer is within chemical fluency.
In the hierarchy of linguistics, literacy denotes a functional competency that allows comprehension and communication, whereas fluency implies a proficiency in which the individual can demonstrate autonomy in acquiring, expressing and even synthesizing knowledge. To simplify, a scientifically illiterate student cannot participate, a literate student can participate passively, and a fluent student can actively participate in scientific discussion and progress.

As Shwartz, Ben-Zvi, and Hofstein (2006a) have demonstrated, many educators and scientists maintain that citizens only need to be scientifically literate, not fluent, to participate in civil matters, such as debates on climate change. However, for chemistry students to be able to learn the science content knowledge necessary to be literate, they must be able to understand and communicate with chemical language. In other words, they must be chemically fluent, which is a skill that will only be cultivated if chemistry curricula explicitly includes supports for chemical language.

It is not a novel idea to equate chemistry with language nor to assert the need to teach chemistry as a language. Many have supported this notion, however few have provided potential solutions for this educational deficiency. Unfortunately, the concept of chemical language has more often been used as a buzzword, even jargon, in education, rather than a clear methodology with substance. It has been championed as necessary, sometimes even revolutionary, yet the truth is that the existing supports for chemical language are superficial and wholly inadequate. To create change anywhere, tools are needed. Inciting change in the current educational climate and curricular standards functions under the same mechanism. Educational tools, such as instructional strategies and curricular approaches, are necessary to incite progress. Therefore, a novel set of multiple instructional strategies must be designed from modifications of bilingual and linguistic educational methods to support the development of chemical language skills.
Project Design

This project aims to develop multiple instructional supports, designed from modifications of bilingual and linguistic educational methods, to promote the development of chemical fluency in chemistry language learners. These chemical language-focused supports will be presented in the form of six language modules. Each module will specifically be designed to align with the chemical language needs in the first six units of a typical Regents Chemistry classroom in New York state. Each module will also feature specifically tailored linguistic strategies and specialized resources, which best support the language needs of the unit. Potential linguistic strategies for use in these modules include translation supports as used in bilingual education, literacy supports such as reading comprehension strategies using analytical etymology, and conversational supports, such as modeling metacognitive behavior and discourse. Specialized resources will also be referenced for each module, such as chemistry language-specific glossaries. Strategies in these modules are intended to be implemented at the beginning of the units or introduction of key concepts whenever possible, in order to preemptively expose the students to the language needs for the rest of the unit. The curricular approach suggested for these modules utilizes a similar classroom environment to bilingual immersion, particularly by presenting parallel expressions of chemical concepts, which is the equivalent of juxtaposed translations. These modules will also aim to create chemistry cultural relevance for student engagement, similar to the goal of foreign language laboratories. For example, the featured etymological glossaries reference the original culture or language behind each word root, which can promote inclusion and student motivation by connecting to students' cultures. Ultimately, these modules will address chemical language needs within the first six units in Regents chemistry, however this approach could also be broadened and applied to all sciences.
Significance

While the potential solution is arguably novel, this problem has been well established in the literature. The multitude of aforementioned authors, who all have asserted that chemistry needs to be taught as a language, each have supported their claims with various foundational arguments. For simplicity, the significance of chemical language instruction will be discussed in two sections. First, to demonstrate that specific language instruction in chemistry is both relevant and applicable, evidence that chemistry is a language will be provided in detail. Second, the negative effect of excluding specific language instruction in chemistry will be demonstrated, in order to implicate that the inclusion and focus on chemical language would improve student learning in chemistry.

The idea that instructional subjects each have their own language is gaining momentum as an educational philosophy. In fact, the international curricular approach of Content Language Integrated Learning (CLIL), which teaches specific subject courses in a secondary language, has championed that very idea as its pedagogical foundation (Nikula, 2015). The CLIL methodology has maintained that the subject-language of the specific content is superlative to the foreign language spoken in the classroom, which has been minimally used as a deemphasized means of instruction (Nikula, 2015).

Specifically, chemistry has been proclaimed as a language by many sources for many years before the development of CLIL (Nikula, 2015). Beyond a mere assertion, the language of chemistry has been deeply analyzed and described by many educators and linguists. Markow (1988) analogously compared chemistry and language with detailed examples of linguistic and scientific equivalents as summarized in Table 1 in the General appendix. His analogy began by describing atomic symbols as the chemical equivalent of the alphabet, because the elements of
the periodic table function as the building blocks of chemical knowledge, just as letters are the building blocks of any language (Markow, 1988). Combinations of individual atomic symbols create molecular formulas, which are chemical analogy to words (Markow, 1988). Chemical 'words' can be further combined to write chemical reactions, which are the equivalent of sentences (Markow, 1988). To fully communicate the chemical concept, the chemical reactions must be stoichiometrically balanced, which is equated with the linguistic need for sentences to be grammatically correct (Markow, 1988). Markow (1988) completed his linguistic analogy by featuring the notion that chemistry students need to be able to 'translate' back and forth between scientific phenomena represented by chemical symbols and described in colloquial English.

Interestingly, Markow has not been the only author to develop and describe the analogy between chemistry and language. Lazlo (2013) has illustrated the same general analogy in exceptional detail, deviating on a few points and progressing beyond previously unexplored areas. His analogy has agreed that the atomic symbol of each element is equivalent to a letter in the alphabet, and by extension, equates each functional group as as a diphthong or syllable (Laszlo, 2013). In further agreement with the preceding analogy, Lazlo (2013) has stated that molecular formulas function as the equivalent of words and that chemical reaction equations also acts as sentences do. From this point forward, Lazlo's analogy has diverged from Markow's. He has explained that one chemical 'word' can be described with a molecular formula, using IUPAC nomenclature or even in a graphical manner, via structural projections (Laszlo, 2013). These alternate representations act as examples of multiple linguistic 'dialects' within chemistry (Laszlo, 2013). Lazlo (2013) has developed multi-layered complexity in his analogy by describing how the 'dialect' of IUPAC molecular names actually function more like sentences rather than as the chemical equivalent of formulas, which act like words. Within IUPAC
chemical nomenclature, the skeleton, substituents and orientation of substituents of a molecule are arranged in a pattern equivalent to the subject, object and verb segments of a sentence (Laszlo, 2013). Lazlo (2013) has proposed a further perspective that 'common' forms of chemical nomenclature, which existed before standardized IUPAC nomenclature, have utilized chemical intermediates as word roots and substituents as prefixes or suffixes, just as complex multisyllabic words do. He even has extended his analogy to metaphor, by depicting enantiomers as word reversals and meso-isomers as palindromes (Laszlo, 2013). Within his analogy, Lazlo (2013) has also warned that just as words can be ambiguous, chemical representations can also be polysemic or inadequate in representing the chemical concepts, such as resonance.

Yet another author, Jacob (2001) has described a detailed analogy that equates chemical symbols to the various operations within linguistics. However, Jacob (2001) has organized his analogy into a hierarchal system of language levels within chemistry as summarized in Table 3 in the general appendix. He has argued that the symbolic language within chemistry acts as the foundational sub-language of chemistry to communicate chemical reactions and systematic changes (Jacob, 2001). Jacob (2001) has defined chemical symbolism as the lowest linguistic level to represent the greatest distinction from colloquial English. The next two levels feature subject-specific vocabulary, such as chemical nomenclature, and abstractors, such as 'atom,' which are two categories of terms not readily used or recognizable in colloquial English (Jacob, 2001). Jacob (2001) has defined the highest linguistic level, which has the greatest similarities to colloquial English, as the philosophical language of chemistry, which combines the use of colloquial English and specific chemical terminology to explain chemical phenomenon as a whole.
While the linguistic analyses of the three aforementioned articles have supported and identified chemistry as a language, it is also necessary to differentiate the language of chemistry from colloquial English. Lazlo (2013) has offered evidence that chemistry is a language unique from English or any other foreign language, by citing the phenomenon that chemists who speak different native tongues can communicate chemistry concepts to each other using chemical language as a lingua franca. Specifically with English, a prominent category of linguistic distinctions are well demonstrated by the endless examples of vocabulary terms that express different meanings depending on their context in science or every-day use. Jaisen (2010) has performed an interview study to investigate the misconceptions regarding the word 'neutral,' which possesses multiple scientific and colloquial meanings, such as a pH value, a state of being uncharged or lack of bias. Analysis of the surveys has shown that students often confused the various scientific meanings with one another, also confused scientific meanings with colloquial ones, and even 'synthesized' their own misconceptualized definitions by compromising between scientific and colloquial meanings (Jaisen, 2010). For example, some students interpreted neutral to mean an unreactive or stable chemical, supposedly by applying the colloquial definition to 'neutralize' the reactivity of the chemical in question (Jaisen, 2010). In a following study, Jasien (2011) has utilized the same methodology as his 2010 study to demonstrate the multiplicity confusions with the word strong, which can indicate concentration, charge, or power depending on the scientific or colloquial context. He has specifically highlighted the prominent and problematic misconception with two scientific definitions of 'strong,' in which students often incorrectly conflate the notions that strong acids have strong bonds (Jaisen, 2011). Jaisen (2010) has also mentioned further challenging scientific vocabulary to be studied, such as radiation, heat
and ionization, which are also likely to cause student confusion and misconceptions due to context-dependent definitions.

Like Jaisen, Lim (2013) also has argued that chemistry is its own language, due to the context-dependent definitions of scientific vocabulary. However, Lim (2013) has provided further evidence that differentiates chemical language from English, by citing research that has demonstrated how ESL and Native English learners both struggle significantly with learning chemistry terminology.

Marais and Jordaan (2000) also have demonstrated through their research that all students, regardless if English is their first language, struggle with symbolic chemical language, which further supports the distinct existence of chemical language. Their study has tested bilingual students' performance on test items featuring chemical symbols and the corresponding vocabulary as a parallel assessment item (Marais & Jordaan, 2000). The assessment data analysis has indicated that "although those whose first language was English had fewer problems, almost all students experienced" difficulty with symbolic chemical language (Marais & Jordaan, 2000).

Aside from demonstrating that the language of chemistry is unique from English, the above research examples also have illustrated how students' struggles with chemical language negatively impact their conceptual learning and performance in chemistry, due to the lack of linguistic support. Specifically, Marais and Jordaan's (2000) comparative analysis of their two assessments have revealed that students demonstrated lower proficiency on the symbol assessment than the vocabulary assessment, which has indicated "that students have greater difficulties with meanings of symbols than with the meanings of words." To explain this phenomenon, the authors have argued "that a student has to go through a large number of
cognitive steps before being able to answer" any associated chemistry questions that feature symbolic chemical language (Marais & Jordaan, 2000). In support of that explanation, Marais and Jordaan (2000) have explicitly outlined the dozen or more sequential cognitive steps that a student must deduce and correctly execute in order to solve a typical example of a chemistry problem. In other words, chemistry students are likely to perform poorly on assessments featuring chemical language, because their cognitive load is overwhelmed with language tasks. Alternatively, the inclusion of language supports within chemistry instruction could improve performance on assessment items that use chemical language, by shifting the focus of the cognitive load to content instead of language.

In both of Jaisen's (2010; 2011) studies, only half of the interviewed students answered all the definitions correctly, except for colloquial example, which had a very high probability of being answered correctly. These results have indicated that students struggle specifically with chemical language, though Jaisen (2010) has attributed these difficulties to student confusion regarding the conceptual multiplicity of chemical terminology." As an extrapolation from his findings, Jasien's (2010) has cited former research, which has documented that "students who could distinguish between the everyday meaning and the scientific use of certain physics terms were more likely to score better on the course exams." This finding further implicates that student learning and performance in chemistry could be improved with chemical language supports, considering that "the fluent use of chemical representations is associated with successful problem solving in chemistry" (Taskin & Bernholt, 2014).

Additionally, Jaisen (2010) also has referenced the documented phenomenon that "slight changes in wording of exam questions [] have a profound effect on the percentage of students correctly answering those questions." While the term is not explicitly used, this statement clearly
alludes to the educational concept of test validity, which maintains that in order to be relevant measures of performance, assessment items should be limited to only the concept being measured. In other words, an assessment item intended to only evaluate chemical content knowledge should not include additional chemical language tasks.

The effects that chemical language has on test performance, and therefore test validity, has been long documented. When testing the same concepts with different language presentations, Cassels and Johnstone (1984) found that students demonstrated higher achievement on the conceptual questions, which had their language simplified through (1) key word replacement with a colloquial term or short explanation or (2) reduction of total word count via rearranged clauses and removal of extraneous information. The authors argued that student performance improved when simplified language lessened the cognitive load on the student, because the students were being tested on chemistry concepts more than language understanding, which is in precise alignment with test validity theory (Cassels & Johnstone, 1984). Similarly, Ver Beek and Louters (1991) have tested the theory that analytical language and chemical language skills are necessary for student success in chemistry, where analytical language skill was defined as the ability to solve word problems, and chemical language skills defined as conceptualization of chemical information. The authors have assessed student performance matched problem sets of a chemistry conceptual problem written with chemical language and the same conceptual problem written only with common language (Ver Beek & Louters, 1991). They have found student average scores to be significantly higher for the problems written with common language, and that difference becomes even more evident when comparing the problems categorically by levels of conceptual complexity (Ver Beek & Louters, 1991). Ver Beek and Louters (1991) have argued that their findings demonstrated how students' lack of
chemical language skills result in poor performance on chemistry assessments, which again is consistent with test validity theory.

Considering the above instances, one might argue that the profound negative effects that poor chemical language clearly has on performance could be negated by eliminating chemical language tasks from chemistry assessments. However, another key concept in test validity pedagogy is the idea that high performance on an unreliable assessment does not indicate proficient student learning. In other words, eliminating chemical language from chemistry assessments would not necessarily improve student learning, despite improving performance. After all, chemical language is a key component of chemistry and therefore is a scientific skill that should be evaluated in students. It would be absurd to eliminate all subject-specific language from any curriculum and its corresponding assessment in order to improve exam scores, just as it would be absurd to eliminate the difficult unit of thermodynamics from a chemistry curriculum for the same reason. To simplify, performance and competency in chemistry is negatively affected by the lack of linguistic supports. Therefore, the obvious solution is to implement specific language instruction in chemistry. In conclusion, linguistic pedagogical strategies should be implemented, which support the acquisition of chemical language skills and the development of chemical fluency, in order to consequently improve student learning of chemistry concepts, as well as performance in chemistry.
Terms

**Bilingual Education:** In the USA, typically refers to teaching academic content in two languages for English Language Learners. However, in the context of this paper, bilingual education refers both to classrooms with ELL students learning subject content in English and to foreign language classrooms, in which native English-speaking students learn a second language.

**Chemical Fluency:** The proficient ability in which an individual can demonstrate autonomy in acquiring, expressing and even synthesizing knowledge through chemical language. This novel term was coined particularly for this paper to indicate academic competency specifically regarding chemical language, which is an area inadequately covered by scientific literacy.

**Chemistry Language Learners (CLL):** A student who is learning the language of chemistry in addition to his or her native language. This novel termed was coined particularly for this paper and is modeled off the term, English Language Learner.

**Code-switching:** The cognitive action of switching between two languages (Rollnick, 2000).

**Content and Language Integrated Learning (CLIL):** A classroom model, in which the academic content is taught in a foreign language (Nikula, 2015).

**English Language Learners (ELL):** A student who is learning the English language in addition to his or her native language (Flores & Smith, 2013).
**Etymology:** The study of word origins throughout history (Sarma, 2004).

**Scientific Literacy:** Defined by the National Science Education Standards (1996) as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity." As defined specifically for this paper, scientific literacy denotes a functional competency that allows comprehension and communication of scientific concepts.

**Specifically Designed Academic Instruction in English (SDAIE):** An educational approach for classrooms with ELL students (Hanes, 2004).
Chapter #2: Literature Review

Ineffective Options for Chemical Language Focused Curricula

In the literature, there have existed only rare examples of chemistry curricula utilize pedagogical strategies that focus on chemical language acquisition. Of the few options, most have presented curricula that rely on a very limited selection of methods that support chemical language, instead of offering differentiated strategies that are specialized towards varied student needs and unique curricular challenges.

Bretz and Meinwald (2002) have designed and implemented college chemistry course for non-science majors, named "The Language of Chemistry." Unfortunately, this course title refers more to an inspirational quote from Nobel laureate, Arthur Kornberg, than an alignment with instructional strategies that support chemical language skills (Bretz & Meinwald, 2002). The authors have carefully chosen and featured fascinating case studies that illustrate how science behaves, in order to align the course materials with the course goal to teach science itself, rather than teach 'about science' (Bretz & Meinwald, 2002). They have aimed the course goals to "empower students from any discipline with the knowledge, language and logic necessary to understand these [case studies]," which indicates the curricular relevance to scientific literacy (Bretz & Meinwald, 2002). However, this reading-focused curriculum is limited as a resource for chemical language fluency, because the language demands of this course have focused on comprehension of general scientific language, rather than acquiring communicative chemical language skills (Bretz & Meinwald, 2002). Despite the course limitations in regards to chemical language acquisition, the use of case studies remains a promising idea that could be adapted in order to support chemical language learning.
Reingold (2005) also has implemented a college level chemistry course with a language focus, as referenced by his curricular goal to support communication with a strategy analogous to foreign language 'immersion' classrooms. To promote scientific communication and literacy, Reingold (2005) has utilized Peer-Led Team Learning (PLTL) in his chemistry course, in which peer groups would practice solving problems together, then communicate the answers and the solution process. The students within his peer groups consistently have demonstrated greater achievement via grade distribution than students who did not participate in the peer groups (Reingold, 2005). However, this improvement could arguably be due to more exposure to chemistry problems and practice, rather than the development of proficient language skills through discourse. The opportunity to communicate chemical information and practice scientific discourse in peer groups is a potentially effective strategy, however this curricular approach has demonstrated the same linguistic limitations as Bretz and Meinwald's course. Reingold's (2005) strategy has created plentiful opportunities to practice chemical language, however the PLTL strategy did not include any specific chemical language supports. Considering that his students have not been given tools or guidance to support their acquisition of chemical language skills, it is pure speculation to assume that the students were able to effectively develop their chemical language skills through this PLTL course, despite the 'immersion' opportunities.

The most promising example of chemistry curricula with a language focus in published research literature has belonged to Hanes, a high school chemistry teacher. She has designed, implemented and briefly describes a chemistry curriculum with three goals: 1) to create a successful science experience for all students, 2) to promote science literacy and 3) to support ESL students (Hanes, 2004). Her curriculum has heavily relied on Specifically Designed Academic Instruction in English (SDAIE) strategies, including visual representations, small
group work, practice opportunities for communication skills, investigations, and directed vocabulary (Hanes, 2004). Hanes (2004) specifically has included strategies that address the importance of decoding in chemistry, as she considers decoding skills to be as essential as translation is in foreign language courses. For example, she has scaffolded decoding skills by explicitly demonstrating the etymology of chemical words, with a distinct focus on Latin roots in order to support her Spanish-speaking ESL students (Hanes, 2004). Hanes (2004) also has promoted the use of Lindamood-Bell language acquisition strategies and the use of everyday vocabulary equivalents to chemical terms, such as cooking language. For writing strategies, she has utilized pre-writing techniques, such as a graphic organizer for key terms, to ease transitions from verbal to written chemical language, and also focuses on creative writing assignments (Hanes, 2004). The inclusion of multiple relevant language strategies that support both different student needs and various conceptual tasks highlight that Hanes’ (2004) chemistry course has demonstrated the greatest alignment and supports for chemical language acquisition of all currently published curricular options. While her curriculum is not elaborately presented, Hanes has provided an excellent starting point for the development of a language-based chemistry curriculum that specifically promotes chemical language in addition to scientific literacy.
Inadequate and Misleading Chemical Language Focused Texts

To support any language-focused chemistry course, examples of language-focused text are necessary to be used throughout the curricula. Unfortunately, the clichéd use of the educationally meaningless, yet trendy phrase, 'the language of chemistry,' is not only heavily prevalent in proposed curricular approaches, but also is highly prominent in the titles of popular chemistry texts. Despite the heavy focus on language that is implied by many catchy titles from both past and present, many texts are woefully insufficient in their ability to support chemical language, because said texts do not actually contain specific information that addresses chemical language acquisition with relevant or effective strategies.

Chemistry Decoded, a college text for non-science majors written by L. W. Fine in 1976, was heavily criticized by Cook (1977), who asserted that the text "[failed] to introduce any new approach" that would reveal the mysteries of chemistry and subsequently, chemical language. He described the conversational tone of the book as casual but rambling, because the author covered tangential topics with irrelevant artwork that is of little importance to chemical language or concepts (Cook, 1977). Ultimately, Cook (1997) condemned the book as being of low educational value, because the misguided presentation negated any effectiveness the text might have provided. Chemistry Decoded received a fairly positive review from Zalot (1982), however that reviewer only highlighted superficial text assets such as catchy chapter titles. Despite its suggestive title, this text clearly did not actually include decoding linguistic strategies or other substantial approaches that support chemical language acquisition.

A more recent text, Organic Chemistry as a Second Language, has been written by David Klein (2004) as a supplemental chemistry text. Holman (2004), a reviewer, has asserted that the informal and conversational tone of the text reduces reading demands to make the text more
accessible to readers. That overall review has been generally positive, however he has maintained that while the text would only function well as a supplement, not as a replacement for a primary lecture texts (Holman, 2004). Holman (2004) did state that "each chapter is driven by a treatment of the language and the background concepts necessary to understand how to read a problem," however this language treatment is implicit and subtle. While an educated reviewer is likely to recognize that this text presents chemistry skills in a systematic method similar to building language skills, it is highly unlikely that an inexperienced student would make that mental connection. Klein (2004) has treated basic chemistry skills as the language of chemistry, but has not made that relationship explicit to the reader, despite the implication in the title. This text is one of the best chemical language texts currently available as it demonstrates great potential to support chemical language acquisition. However, to be truly effective, Klein's text would need to 1) be developed into an adequate primary textbook that demonstrates conceptual connections to the included chemical language skills and 2) also explicitly present the included chemical skill strategies as linguistic supports.
Scientific Literacy Strategies with Adaption Potential for Chemical Fluency

Even if an adequate text that supports chemical language acquisition is featured in a chemistry curricula, the students will still need scientific literacy supports to aid their ability to understand the concepts being presented in the readings. A broad variety of scientific literacy supports do currently exist in the literature. However, these strategies support scientific literacy, not necessarily chemical fluency. In order to support chemical language skills, these strategies would need to be adjusted via chemistry-targeted adaptations.

Within this first category of supports, scientific literacy strategies, exist a wide variety of specific strategies, all which can be adapted to suit chemical language needs. Many literacy strategies concern vocabulary, the basic building blocks of any language. However, few strategies exist that are specifically designed for scientific vocabulary, despite the distinct need for such support. Jaisen (2010; 2011) has clearly documented students' struggle with conflicting definitions of chemistry terminology in his two survey-based studies, in which he has interviewed students regarding multiplicity confusions caused by the terms 'neutral' and 'strong'. From the initial study, Jaisen (2010) has suggested that educators should explicitly explain differences in colloquial and multiple scientific meanings in special terms during instruction by providing the "required vocabulary and... skills to... contextualize... problematic vocabulary." Despite his calls for explicit instruction, Jaisen unfortunately has not actually offer any explicit strategies to elucidate between conflicting verbal or written definitions of chemistry terms.

Another significant area of literacy strategies consists of reading comprehension supports, which could be adapted to promote scientific literacy. Interestingly, Pyburn, Pazicni, Benassi and Tappin (2013) have argued that any research-supported strategies that improve general comprehension, such as scaffolding reading strategies, would be beneficial within
chemistry curricula in regards to student performance. This assertion is based upon the performance gaps they have observed within their research, which indicates a significant correlation between general language comprehension ability and chemistry performance (Pyburn, Pazicni, Benassi & Tappin, 2013). Pyburn, Pazicni, Benassi & Tappin (2013) has further been able to demonstrate that "comprehension skill partially compensates for deficits in prior knowledge" in chemistry by highlighting how students with higher levels of comprehension skills performed better than students with low levels of comprehension skills across all levels of prior chemistry knowledge. The authors have conceded that comprehension ability does not "completely compensate for low prior knowledge", though they have considered comprehension ability to be distinctly advantageous in chemistry (Pyburn, Pazicni, Benassi & Tappin, 2013). However, they have concluded that all chemistry curricula should ideally "include both content and the development of language comprehension skill" in order to better support student learning and success in chemistry (Pyburn, Pazicni, Benassi & Tappin, 2013).

Within reading comprehension, the use of metacognition strategies is common, and thus these strategies could be adjusted for chemistry. Specifically, Laszlo (2013) has argued that heuristic cognition should be utilized within chemistry, because that problem-solving process, which is necessary for linguistic understanding, can also be applied to chemical language. In a case study, Lapp, Fisher, and Grant (2008) have observed the beneficial use of reading comprehension supports, including metacognition strategies, for a text on chemical reactions within a general science classroom. The cooperating teacher has utilized "interactive comprehension instruction through think-alouds based on shared readings" and also highlighted text structures, features and vocabulary in order to promote student comprehension (Lapp, Fisher, & Grant, 2008). Further, the teacher has scaffolded metacognitive reading strategies
often using research-supported methods, such as the Predict-Observe-Explain (POE) strategy, which the authors considered to be quantitatively successful (Lapp, Fisher, & Grant, 2008).

The aforementioned supports for reading comprehension strategies in chemistry provide a promising start. However, all above supports are either highly generalized, applied to general science classrooms rather than specifically chemistry classes, or based on predictive implications from related research without confirmatory evidence. Thus, the adaptation of scientific literacy strategies for specific use within chemistry in order to support chemical language acquisition remains an open possibility for newly devised strategies and research.
Bilingual Strategies with Adaption Potential for Chemical Fluency

Chemical language skill strategies do not need to be limited to only the realm of science supports. General language supports also have the potential to be adapted and specified regarding chemistry language needs. Considering that chemical language relies heavily on abstract symbolism, it is not surprising that many students find chemical language to be just as confusing and alien as a foreign language. As such, it seems highly appropriate that bilingual strategies are another category of supports that can be implemented with some adjustment for chemical language acquisition.

In bilingual education, translation between a second language and one's native tongue is a skill referred to as code-switching (Rollnick, 2000). This multilingual process, which is highly applicable in chemistry, can be summarized with the following cognitive steps that a student must execute when solving chemistry problems with scientific vocabulary. First, the student must retain both the symbolic representation and the specific scientific vocabulary term in order to process the provided chemical language into a comprehensible understanding of the underlying concept in English. If the student is able to extract the main concept from the text, and solve for the answer conceptually in English, then they can finally translate their conceptual understanding in English back to chemical language. Flores and Smith (2013) have described that same process in regards to ELL students in chemistry classrooms, and describe the multi-step translation process of code-switching as a heavy burden on a student's cognitive load. As a support, they have suggested that extra time and encouraging cooperative peer efforts in translation can ease student struggles with code-switching, which is a notion applicable to ELL students, and consequently, also applies to chemistry language learners (Flores & Smith, 2013). Rollnick (2000) also has reported on successful code-switching supports as used in a bilingual
chemistry classroom. He has described observations in which a chemistry teacher clearly and explicitly modeled the process of code-switching, while also using code-switching to provide conceptual context to the reading, as part of a shared read-aloud strategy (Rollnick, 2000). This strategy is essentially a bilingual extension to the metacognitive reading comprehension strategy which was observed by Lapp, Fisher, and Grant (2008), as described in the literacy supports section above.

Aside from metacognitive strategies, another method to support bilingual code-switching skills is by simultaneously presenting parallel representations of chemical concepts. As described in a previous section, the language of chemistry has multiple levels that range from abstract symbolism, which can only be visually depicted, to spoken language that shares some similarities, though remains distinct, from colloquial English (Jacob, 2001). These levels of chemical language correspond with the multiple realms of chemistry: macroscopic, submicroscopic and symbolic. Macroscopic phenomena can be described with subject-specific and sometimes even general terminology, whereas submicroscopic phenomena can be described with either subject-specific vocabulary or symbolic chemical depictions. Interestingly, Laszlo (2013) has interpreted these linguistic distinctions in chemistry as equivalents to different dialects of a single language. While other authors have not used the label of 'dialect,' many do support the notion of parallel representation of chemical representations. Flores and Smith (2013) have suggested that chemistry concepts should be presented in a way that explicitly connects the multiple realms of chemistry, in order to promote comprehension across the macroscopic, submicroscopic and symbolic linguistic representations. Jaisen (2011) also has supported this idea, and specifically describes the concrete strategy of providing a parallel
representation of molecular drawing as supplements to verbal definitions. This strategy is analogous to the juxtaposition of vocabulary translations within any bilingual classroom.

Moving beyond the conceptual linking of code-switching to a more analytical approach, decoding and encoding is another indispensable skillset within bilingual education. Linguistically, the majority of words in modern languages are built from a collection of morphemes, or word stems, which is the very foundation of etymology. The same generalization applies to chemistry. Indeed, almost all words used in chemistry come from Latin, Greek, English, German and French linguistic roots (Sarma, 2004). When approached with a new vocabulary term, the analytical use of etymological decoding can provide students with predictive power regarding words they have not seen before, both in chemistry and other subjects (Sarma, 2004). Loyson (2009; 2010) has provided an abundance of etymological examples in chemistry with two comprehensive reports that demonstrate both Greek and Latin origins of chemistry vocabulary. For example, dozens of elemental names and abbreviated symbols originate from Latin linguistic roots or references to Greek mythology (Loyson, 2009; Loyson, 2010). Most numerical prefixes in organic chemical nomenclature, such as pent-, hex- and oct- have roots in Greek, whereas Latin numerals are utilized in inorganic nomenclature. Loyson (2009; 2010) has listed how spatial orientations, structural descriptions and chemical properties of molecules, even names of laboratory techniques are derived from morphemes of the classical languages. All of this etymological data and more can be applied to newly designed decoding strategies for chemical language.

Sarma (2004) has taken decoding possibilities through etymology one step further in chemistry by demonstrating how morphemes can illuminate many conceptual relationships between chemical vocabulary. In her report, she has organized the genres of chemical terms into
concepts and their contradictory counterparts, structural descriptions, matched pairs with opposing properties, dual concepts, numerical terms in nomenclature and color terminology, giving dozens of examples in each sub-sector (Sarma, 2004). Therefore, etymological analysis as a decoding strategy can aid concept comprehension in chemistry, not just by revealing the meaning of individual terms, but by connecting concepts across the macroscopic, submicroscopic and symbolic scales and corresponding linguistic dialects within chemistry.

The above etymological resources did include any research that implemented instructional methods using said etymological data, and therefore do not offer any evidence towards the efficacy of a etymology-specific decoding strategy. However, Hanes (2004) has presented a case study in which she designed and implemented a chemistry curriculum that utilized linguistic supports, including etymology, which did demonstrate qualitative evidence towards the efficacy of decoding skills in chemistry. Her curriculum has heavily relied on Specifically Designed Academic Instruction in English (SDAIE) strategies using a variety of supports, yet also emphasized the importance of decoding skills in chemistry (Hanes, 2004). To scaffold these decoding skills, Hanes (2004) has explicitly modeled her analytical process to decode chemical words using etymology with a focus on Latin roots, which has demonstrated positive improvement among her Spanish-speaking ELL students. These decoding supports could easily be effectively applied to the general classroom populace, rather than limited to only ELL students, in order to support chemical language acquisition.

Aside from etymology, decoding and encoding can be used in other areas of chemical language as well, particularly with abstract symbolism, such as chemical formulas. Bradley and Steenberg (2006) have implemented decoding and encoding strategies into a bilingual chemistry course to support "students’ ability to decode symbolic chemical formulae to names of
compounds and to encode names of compounds to symbolic formulae" for ionic compounds. The authors have promoted the following coding supports for future research or use in chemistry, noting that teachers often decode and encode intuitively, and thus need a strategy to make their automatic coding strategies explicit to the students (Bradley & Steenberg, 2006). For decoding, Bradley and Steenberg (2006) have described a 4-step strategy to translate from chemical formula to name by 1) identifying individual atom names, 2) organizing the atoms from electropositive to electronegative, 3) note the ratio of atoms, and 4) formulate the name. For encoding, they have similarly described an explicit 4-step strategy to translate from chemical name to formula by 1) identify symbols of all atoms and polyatomic ions, 2) deduce electropositivity or electronegativity due to position in the name, 3) determine ratio from valency or nomenclature clues, and 4) create the formula (Bradley & Steenberg, 2006). The authors have asserted that utilizing this explicit step-wise approach not only provides students with supportive 'translation' tools, but also allows for an accurate diagnosis of problematic tasks within the decoding or encoding process for individual students (Bradley & Steenberg, 2006).

Taskin and Bernholt (2014) also have discussed student challenges with interpreting chemical formulae in regards to decoding and encoding skills. By analyzing student comprehension regarding different types of chemical formula and student application of operational tasks involving formulas, they have highlighted three main difficulties; "language-based problems, problems due to conceptual understanding, and problems due to inadequate selection and interpretation of formulae" (Taskin & Bernholt, 2014). Taskin and Bernholt (2014) have explained that chemical "formulae are a highly abstract and specialized [form of] chemical language expressed in the very reduced form of a symbol or an image." Therefore, in order to reduce chemical information into the abbreviation form of a chemical formula, a student must
have adequate encoding skills, just as the inverse process requires adequate decoding skills (Taskin & Bernholt, 2014). The authors have explained that despite their frequent use in the chemistry classroom, chemical formulae are taught in a way that does not adequately demonstrate their purpose or methods of use, which is highly problematic, considering that "the fluent use of chemical representations is associated with successful problem solving in chemistry" (Taskin & Bernholt, 2014). To address these issues, Taskin and Bernholt (2014) have asserted that "representational competence can be fostered by explicitly engaging students in the creation of various representations and in reflection on their meaning." Thus, they have implemented reflective tasks within chemistry in order to support decoding and encoding skills by "[requiring] students to think about and communicate not only their conceptual understanding but also their understanding of the language properties" (Taskin & Bernholt, 2014). The authors have presented a few examples of such reflective tasks that are designed to demonstrate student understanding, but also offer the students the opportunity to design a preferred representation with their own encoding methods or to hypothesize why scientists use existing chemical representations (Taskin & Bernholt, 2014).

Many strategies exist that support the multilingual skills of code-switching, decoding and encoding within bilingual classrooms for ELL students. However, these effective methods needs not be limited to only ELL students or CLIL chemistry classrooms. All chemistry students should be considered chemistry language learners (CLL) and could also benefit from explicit coding strategies. Ultimately, these bilingual instructional strategies can be specifically adapted to support chemical language acquisition for all students in every chemistry classroom under a similar philosophy to CLIL classrooms.
Conversational Strategies with Adaption Potential for Chemical Fluency

Aside from strategies to promote translation skills, another indispensable instruction method that is common in all bilingual classrooms is the promotion of conversation in order to improve language acquisition and competence. Similarly, conversation strategies using chemical language can also be implemented within chemistry classrooms with the same goals of encouraging comfort and increasing linguistic competence.

Most conversational strategies within bilingual education are justified under the concept of immersion, in which constant exposure to a foreign language necessitates the development of student ability to use that language. Reingold (2005) has reflected that school of thought by referencing how strategies analogous to foreign language ‘immersion’ classrooms could benefit chemistry and by providing conversational opportunities in his college level chemistry class through Peer-Led Team Learning (PLTL) discussion groups as described earlier. This open opportunity to communicate chemical information and solution processes in peer groups is a powerful idea, yet it could be improved further with the inclusion of communication supports for his students within the peer groups.

Supports for conversation that specifically provide tools for autonomous student use are often founded on teacher modeling. In a case study, Lapp, Fisher, and Grant (2008) have primarily described how the teacher scaffolded metacognitive strategies for reading, however they also mentioned similar modeling supports for general discourse. In a dialogue focused case study, Warfa, Roehrig, Schneider, and Nyachwaya (2014) have "examined the role of teacher-initiated discourses in developing students’ representational fluency" through discussion and dialogue observations on aqueous ionic solutions in a POGIL-based chemistry classroom. The authors have identified and analyzed the educational impact of two types of "teacher-initiated
discourse...: monologic and dialogic," in which monologic and dialogic discourse are defined by the idealogical meanings of reinforcing the one belief versus encouraging multiple perspectives, rather than the structural definition of one speaker versus a multi-person discussion (Warfa, Roehrig, Schneider, & Nyachwaya, 2014). Further, they also have highlighted "specific conversational strategies", also referred to as "teacher discursive moves", which were particularly successful in "facilitating students’ representational fluency in chemistry" (Warfa, Roehrig, Schneider, & Nyachwaya, 2014). Warfa, Roehrig, Schneider, and Nyachwaya (2014) have highlighted communicative, confirming, generative, instructional, linking, modeling, reorienting, and sharing as the eight types of strategies utilized by teachers to communicate essential chemical knowledge. However, the authors have observed that the specific move types were often associated with discourse type, namely "confirming and reorienting moves were mainly evident in dialogic discourses, whereas generative, sharing, and modeling moves were mainly present in monologic discourse" (Warfa, Roehrig, Schneider, & Nyachwaya, 2014). They have also noted that some moves were prevalently observed in both discourse types, namely "communicative, instructional, and linking moves" (Warfa, Roehrig, Schneider, & Nyachwaya, 2014). Warfa, Roehrig, Schneider, and Nyachwaya (2014) have concluded, due to their observations, that student learning was more positively impacted by dialogic discourse than monologic, as shown by "shifts in student and whole group thinking following teacher's dialogic discourse, but not monologic discourse." Due to their findings, the authors have suggested that educators should utilize "communicative, linking, reorienting, and confirming moves" during discussion facilitation as models of effective dialogue "in order to develop students’ representational fluency of chemical ideas" (Warfa, Roehrig, Schneider, & Nyachwaya, 2014).
Similar to teacher modeling, other strategies that have been shown to support conversation in chemistry classrooms include linguistic structural templates. For example, Rollnick (2000) has observed successful implementation of IRF (initiation, response, feedback) sequences and oral cloze in bilingual chemistry classrooms. Taskin and Bernholt (2014) have suggested the implementation of a linguistic structural pattern that supports communication with greater freedom regarding student speech. Though originally aimed to promote encoding and decoding skills, these reflective tasks could also provide a template for peer-to-peer dialogue (Taskin & Bernholt, 2014).

While the aforementioned conversational strategies support chemical language acquisition in terms of ability, they do not address issues of motivation and engagement. To encourage student interest, and thus willingness to communicate using chemical language, subject matter must be presented in a way that connects to their experiences and beliefs. Markow (1988) agreed that chemistry teachers need to make chemistry relevant to students, parallel to how foreign language teachers provide relevance in bilingual education. However, he argued that the resulting associations that student would develop with chemistry could aid knowledge retention, rather than focusing on the idea that interested students are likely to discuss chemistry concepts more (Markow, 1988). The creation of cultural relevance in chemistry is also an important concept in CLIL philosophy, which is founded on three areas of focus: "content-learning, subject-language and subject-culture" (Nikula, 2015). This idea of subject-culture is an untapped opportunity in many chemistry classrooms. Flores and Smith (2013) have commented that promoting a student's sense of cultural identity within the chemistry classroom provides motivational support by creating a multicultural, inclusive learning environment. Considering that chemistry is a global industry and a universal phenomenon, there exist many authentic and
relevant connections between chemistry and every student's life. Therefore, there are many opportunities to foster an inclusive subject-culture in a chemistry classroom that could motivate students' interest and involvement in a way that encourages participation in classroom conversations that use chemical language.

If teachers can encourage students to engage in dialogue with conversational strategies in chemistry, then every student's chemical language competence will be bolstered. In order to achieve this, teachers need conversational supports that are applicable to chemistry, such as adaptations or direct implementations of the aforementioned conversational strategies.
Specialized Linguistic Resources with Adaption Potential for Chemical Fluency

In order to support bilingual, conversational and literacy instructional strategies, which have been specifically adapted for chemical language, specialized resources beyond a single classroom textbook are absolutely necessary. Supplementing other strategies with specialized resources provides students with tools they can use autonomously use for self-directed learning.

One of the best ways for students to self-teach is by providing them plentiful options of accessible, interesting reading materials. Bretz and Meinwald (2002) utilized this strategies by integrated case studies into their college-level chemistry curriculum. Unfortunately, acceptable readings for chemistry case studies can be difficult to find, especially for high school curricula. Chemistry reading materials often cover topics beyond the scope of high school chemistry and are written with complex scientific language that is highly challenging for high-school level readers. To remedy this issue, Phillips and Norris (2009) "recommend the use of adapted primary literature," which are modified versions of scientific texts. Adapted primary literature is written in a way that simplifies the scientific language and breadth of concepts in a way that is more accessible to students. However, adapted primary literature could also be developed as a linguistic resource that also includes specific chemical language supports beyond simplification.

One well-known resource that supports reading ability, is the glossary, which is often utilized within chemistry, yet arguably not to its full potential. Glossaries in the back of most chemistry textbooks tend to be simplistic text-only resources. However, Marais and Jordaan (2000) have suggested that glossaries for chemistry symbols should be utilized, which could further be adapted to include symbols and text as parallel representations of chemistry concepts. Glossaries also do not need to remain limited to the printed page, instead they can capitalize on emerging forms of technology. A study by Rees, Bruce and Nolan (2013), which has utilized
various strategies to enhance scientific literacy within a chemistry course, resulted in the compilation of a multi-media e-glossary. That e-glossary contains a combination of instructor and student contributed entries, such as technical vocabulary, explanations of etymological roots, and even mnemonic devices, which were represented with a wide variety of media, such as video, podcast and animations in order to appeal to different learner types (Rees, Bruce, & Nolan, 2013). Rees, Bruce and Nolan (2013) have reported that student use of and contributions to the e-glossary, as well as survey responses, indicated a positive impact on learning. In a following study, Rees, Bruce, and Bradley (2014) have expanded upon the previous e-glossary to create the FOCUS (Foundation Corpus) project, which was a searchable database with different search tools, such as keyword definition comparisons and word clouds. The authors have justified this database with the argument that students already commonly use their smart phones to search for definitions to chemistry terminology, which does not guarantee that students will find the correct definition, depending on parallel colloquial terms or what resource the students use (Rees, Bruce, & Bradley, 2014). They have asserted that the FOCUS project can be featured in many classroom strategies in order to enhance subject-specific language comprehension in chemistry students (Rees, Bruce, & Bradley, 2014). For example, this searchable database can provide scientific writing assistance for student laboratory reports through its highly specialized technical glossary, which even can analyze the etymology of scientific vocabulary (Rees, Bruce, & Bradley, 2014). In fact, a glossary could be designed to only comprehensively feature etymological stems common in chemistry terminology in order to support student decoding and encoding skills.

Another category of linguistic resources that can be adopted in chemistry are various templates for scientific writing support. Flores and Smith (2013) have suggested that teacher
adopt the use of supplemental linguistically-supportive materials, such as Cornell notes and word walls, because they can promote code-switching skills. Hanes (2004) also has supported her students' code-switching skills by utilizing other pre-writing resources in her case study, such as graphic organizers for key terms and directed vocabulary.

Lastly, specialized assessment items offer incredible educational potential as linguistic resources for teachers to evaluate student ability regarding chemical language. For their research, Marais and Jordaan (2000) have developed an assessment to test student understanding of chemistry symbols, which could be adapted for instruction rather than research. By individually testing separate aspects of chemical language, teachers could harness specialized assessments as a diagnostic tool regarding student ability in chemical language. Bradley and Steenberg (2006) have supported a similar assertion by arguing that the evaluation of student progress solving a step-wise chemistry problem can accurately reveal which specific steps are most problematic and therefore which individual student skills require extra support.

The aforementioned examples of linguistic resource categories describe only a few options out of the dozens of varied linguistic resources available in education. With minor adjustments, all of these linguistic resources could provide great potential for adoption into chemistry curricula in order to support chemical language acquisition. In fact, this notion rings true for all the categories of supports described herein. Any linguistic support, whether bilingual, conversational and literacy-based, can be adjusted in order to support chemical language skills in a language-focused chemistry classroom. Not only is adjustment of linguistic strategies possible, it is necessary to support learning in chemistry classrooms. Fluent use of the language of chemistry is integral for student mastery and comprehension of chemistry concepts. A revolution within chemistry classrooms could be incited, if the educational tools necessary for
chemical language skills were made available. Therefore, the next step in revolutionizing chemistry education through chemical language fluency requires that a broad variety of instructional strategies, which support the chemical language skills necessary for fluency, be developed from existing bilingual and linguistic strategies.
Chapter #3: Project

Inspiration

As detailed in the introduction and literary review, there exists a distinct need in chemical education for instructional tools that support chemical language acquisition and develop chemical fluency in students. As a bilingual speaker, the author designed a novel set of varied chemical language instructional strategies, which are based on modifications of research-supported bilingual and linguistic educational methods. However, tools alone cannot remedy the lack of language focus in chemistry; educators and students must develop an awareness of chemical language and recognize how chemical language manifests itself within all units of a chemistry curriculum. Therefore, this project does not just provide instructional strategies, but it also offers a curricular approach towards developing chemical fluency.
Curricular Approach Justification

As described in the Significance section of Chapter One, there are three scholars mentioned, whose works are foundational to the curricular approach of this project.

First, there are Markow (1988) and Lazlo (2013), who both developed a detailed analogy between linguistic elements and chemical expressions. The analogies of both authors agree on most foundational points, which are summarized in Table 1 in the General appendix. However, the two analogies deviate slightly in certain areas. Markow (1988) completed his linguistic analogy by featuring the notion that chemistry students need to be able to 'translate' back and forth between scientific phenomena represented by chemical symbols and described in colloquial English. However, Lazlo's (2013) analogy progressed with further detail, by considering functional groups to be diphthongs, IUPAC nomenclature, molecular formulas and structural projections to be dialects, and even equating mesomers as palindromes. However, this segment of his analogy moves beyond the scope of the Regents chemistry curriculum and thus is not addressed in this project.

Second, there is Jacob (2001), who developed a detailed analogy between chemical symbols and the hierarchal operations within linguistics. Essentially, Jacob organizes the various linguistic and symbolic expressions of chemical knowledge in an order that compliments the Common Core levels of language as summarized in Table 3 in the general appendix.

The curricular approach of this project can be summarized as the acceptance of chemistry as a language through the recognition of linguistics elements of chemical language within the Regents curriculum and the application of a translation-focused mindset to chemical knowledge.

From Markow (1988) and Lazlo's (2013) interpretations of the linguistic elements within chemistry, the author has revised said analogy to best support the language needs of the Regents
chemistry curriculum. The greatest difference between this author's version and Markow's or Lazlo's original version is the addition of electron configurations. Additionally, any analogous linguistics elements that typically fall outside the scope of Regents content are excluded. This final revision of this project's linguistic analogy is summarized in Table 4 in the appendix.

In addition to adapting the linguistic analogy to Regents content, the author also highlighted which linguistic elements appear most prominently in which typical unit divisions of the Regents Chemistry curriculum. By identifying the language needs of each unit, the author was able to develop six language modules that were specifically designed to support language needs as they occur across the sequence of chemistry units. Typical unit divisions of the Regents chemistry curricula in New York are summarized in Table 2 and the author's division of language needs of each typical Regents unit are summarized in Table 5 of the appendix.

Each of the six developed modules rely on the application of translation-focused strategies, which are rooted in Markow's (1988) call for teaching chemistry students translation skills. However, this translation mindset does not only apply to the translation between chemistry and colloquial English. It also applies to the hierarchal realms of chemistry, which curiously compliment Jacob's (2011) levels of chemical language, as summarized in Table 6 in the appendix. Conceptually, chemistry can be observed on the macroscopic scale or theorized on the submicroscopic scale. A single phenomena that occurs on the macroscopic and submicroscopic scale are frequently communicated using different language expressions. Therefore, students of chemistry must be able to translate between different expressions of chemical language in order to understand how chemical phenomena occur on different scales, in addition to also being able to translate between chemical language and colloquial English.
Module Format Rationale

As stated above, the author developed six language modules, which address chemical language needs within each chemistry unit in order to support student acquisition of chemical language skills and fluency. The specific format of each module is detailed in Module Design and application of the modules is outlined in Suggested Use. Rationale behind the general form and application of the modules, particularly the effectiveness of translation support in easing cognitive load, improving performance and assessment, will be described briefly here. However, greater detail can be found in the literature review in the Bilingual Strategies section.

In alignment with the curricular approach, all strategies within each module support student ability to translate between chemical language and colloquial English, as well as between the various expression forms of chemical language. In order to develop student translation skills, parallel representation of chemical expressions will be promoted, both in classroom presence, such as informational posters, supplemental materials, and notes with glossaries, and also in class discussion or general discourse. This strategy creates a classroom environment similar to immersion approaches used in bilingual education.

Translation has been the primary strategy in bilingual classrooms for decades due to its effectiveness, and the benefits of translation support apply to chemistry classrooms as well. Marais and Jordaan (2000) demonstrated that eliminating excess chemical symbols in assessment improved student performance. Arguably, their chemistry evaluations also show increased accuracy in measuring student learning, by transferring focus on symbolic language to focus on conceptual understanding (Marais & Jordaan, 2000). Marais and Jordaan (2000) argued that the addition of symbolic language burdens student cognitive load, by dividing focus between learning concepts and language simultaneously. They further suggested that language needs in
chemistry should be provided in front-loading strategies, to avoid the division of focus later when concepts are presented (Marais & Jordaan, 2000). In accordance with this finding, the author heavily suggests that, whenever possible, translation supports within the modules should be used preemptively in order to ease cognitive load of language needs during conceptual learning. The author also asserts that students should be actively encouraged to frequently translate between chemical language and colloquial English, in order for the educator to more accurately assess and affect their learning.

While Marais and Jordaan's (2000) studies focused on the elimination of symbolic language within chemistry, chemical symbols are a necessary part of chemistry curricula and cannot just be excluded. In order to support understanding of abstract chemical symbols, multiple authors have discussed their versions of translation skills; Rollnick (2000) refers to this cognitive operation as code-switching, however other authors often use the terms decoding and encoding. Many authors promote teaching translation skills through scaffolding and metacognition, whereas several others suggest parallel representation and etymological analysis. All of these strategies and many more both within and beyond bilingual strategies, are applied within the various instructional supports that can be found across the six language modules. For further detail, see Individual Strategies and Supports Rationale below.
Rationale for Individual Strategies & Supports within Modules

Every strategy found within the six language modules are all supported by current education research with their rationale falling under the categories of scientific literacy, bilingual and conversational supports or specialized resources, which is detailed in the literature review. Specifically, all instructional activities developed for this project can also be categorized as one of the following six types of strategies: Analysis of Linguistic Representations and Symbols, Analysis of Pictorial Representations, Summation and (Re)Organization of Information, Visual Representations of Abstract Concepts, Creative Expression of Abstract Concepts and Reflective Tasks regarding Abstract Concepts. Each of these categories will be detailed below with explanations of the underlying rationale and a list of the applicable instructional activities. Note that some instructional activities fall under multiple categories, however they will only be listed under the category that is most applicable.

Analysis of Linguistic Representations and Symbols

Strategies that classify as Analysis of Linguistic Representations include any instructional activities that feature formulaic guidance, such as word-stem or question-stem analysis, particularly with reference to a supporting glossary, such as the etymology, symbol or vocabulary glossary, for instruction regarding vocabulary terms, electron configuration, molecular formulas, IUPAC nomenclature and other reading. Titles of specific strategies are listed by module below.

Module #1: Analysis of Morphemes used in Scientific Terminology, Unit Conversions Decoded, Side Note Basic Symbols Key
Module #2: Analysis of Atomic Morphemes and Elemental Etymology, Alchemic Etymology, Side Note Atomic Symbols Key, Making Nuclear Symbols just Clear Symbols
Module #3: Side Note Electron Configurations Key
Module #4: Analysis of Bonding Morphemes
Module #5: Analysis of IUPAC Prefixes and Suffixes, Chemical Formula Poker or Gin Rummy, Side Note Molecular Formulas Key, Side Note IUPAC Nomenclature Key,
Module #6: Analysis of Reaction Morphemes, Side Note Chemical Equations Key

When distilled down to the simplest and most recognizable educational theory, the above strategies reflects basic reading comprehension rationale, which is a commonly accepted support for scientific literacy. In fact, the research of Pyburn, Pazicni, Benassi and Tappin (2013) suggests that scaffolding reading strategies not only improves student performance, but that well developed "comprehension skill partially compensates for deficits in prior knowledge" as well.

Many of the above strategies utilize etymological analysis, which can act as memory aids for vocabulary and can even empower students to deduce the definitions of scientific terms that they have never been exposed to before (Sarma, 2004). Additionally, Sarma (2004) argues that conceptual understanding can be further improved, because morpheme analysis can also reveal relationships and contradictions between chemical vocabulary, which Jaisen (2011) repeatedly endorses as a necessity for scientific literacy. The etymological glossary developed for this project draws significantly from both Sarma (2004) and Loyson's (2009; 2010) extensive lists of scientific word roots, which is a specialized resource supported by both Marais and Jordan (2000) and Rees, Bruce and Nolan (2013).

However, the above strategies reach beyond typical reading strategies for academic English, such as etymology analysis and glossaries, by extending into the metacognitive and bilingual fundamentals of code-switching as a strategy for interpreting abstract chemical symbols (Rollnick, 2000). Just as a word can be analytically separated into etymological morphemes, chemical formulas can also be decoded into simpler chunks of information. In particular, Bradley and Steenberg (2006) promote this approach, by highlighting the need for educators to explicitly outline for their students the metacognitive, code-switching process that they engage in
intuitively and automatically. This project includes some strategies, particularly the etymological analysis sections in the etymology glossaries, that detail a step-wise decoding method, very similar to Bradley and Steenberg's 4-step coding approach (2006). However, some strategies are not explicitly outlined in order to allow educators, who wish to use this project, the opportunity to identify their own intuitive methods and develop those methods into their own code-switching instructions.

**Analysis of Pictorial Representations**

Strategies that classify as Analysis of Pictorial Representations include any instructional activities that feature formulaic guidance for drawing or interpreting diagrams, models and visual depictions, or that provide support for student use of diagrams and charts found in the Regents Chemistry Reference Tables, for instruction regarding atomic models, molecular structures and other visualizations. Titles of specific strategies are listed by module below.

*Module #1*: Unit Conversions Decoded,
*Module #2*: Color-coding the Periodic Table and Table S, Side Note Atomic Models Key,
*Module #3*: Color-coding the Periodic Table for Electron Configurations
*Module #4*: Extrapolations from Side Note Atomic Models Key
*Module #5*: Cut & Paste Reference Posters
*Module #6*: An Easy "Cheat" for Reactions

Few consider diagrams and graphs to be language, however they are complex combinations of symbols that can convey vast amounts of vital information. Personally, this author considers the Periodic Table of Elements to be the chemical equivalent of the legendary Rosetta stone. In order to extract information from the Periodic Table or other tables within the Regents Reference packet, students need explicit step-wise instructions that are highly similar to Bradley and Steenberg's 4-step coding approach (2006). Code-switching strategies that apply to
symbolic chemical language as described for the strategies above, also apply to graphs that contain fewer, yet many of the same chemical symbols (Rollnick, 2000).

Aside from focusing on the use of metacognitive processes to interpret the condensed information contained within graphs, graphs themselves can be classified as specialized resources, which are promoted by multiple researchers in educational research as vital to improving performance (Marais and Jordan, 2000; Rees, Bruce and Nolan, 2013). However, this author asserts that one of the most powerful specialized resources for Regents chemistry is readily provided to all New York chemistry students; the Regents Reference tables, which is a packet filled with diagrams, charts and other forms of graphic organizers. As emphasized above, students simply need to be taught how to navigate this remarkable source of information. While this author has not found any research that specifically studies student use of the Regents Reference tables, both Flores and Smith (2013) and Hanes (2004) indicate that use of supporting materials and specialized resources, such as graphic organizers, actually promotes code-switching skills in chemistry problem-solving.

**Summation and (Re)organization of Information**

Strategies that classify as Summation and (Re)organization of Information include any instructional activities that feature the use graphic organizers, such as Frayer models and hierarchal charts, or the creation of alternate depictions of existing graphic organizers, namely the periodic table, for instruction that demonstrates relationships and differences between various concepts. Titles of specific strategies are listed by module below.

*Module #1:* Types of Energy in Toys  
*Module #2:* Scalar Depictions of Elements, Simplified Versions of the Periodic Table, Emphasized Trends in the Periodic Table, Alternative Depictions of the Periodic Table, Atomic History Graphic Organizer, Alien Periodic Table  
*Module #3:* How "Bohr"ing are Lewis Dot Diagrams?, Electron Notation Types Together
Module #4: Intermolecular Forces Hierarchy, Determining Bond Type with Multiple Models
Module #5: States of Matter Hierarchy, Different Depictions - Same Compound,
Module #6: Formula Forks

The primary educational goal that is supported by the use of graphic organizers is the creation of conceptual links between parallel representations of abstract concepts. In other words, when students are presented with adjacent, equivalent codes simultaneously, in this case within a graphic organizer, the relationships between the abstract concepts are illuminated and thus student code-switching abilities are reinforced (Flores and Smith, 2013; Hanes, 2004). Additionally, graphic organizers can be used to demonstrate the differences between scientific and colloquial meanings, which is a major source of misconceptions as studied by Jaisen (2011). Graphic organizers can even be used to clarify conflated scientific terms that Jaisen (2011) has also cautioned educators to carefully and explicitly differentiate between in order to improve scientific literacy.

Beyond promoting conceptual links through summarization, the strategies of this project also empower students to reorganize the existing graphic organizers into other formats which students are comfortable navigating. Multiple authors suggest that the Periodic Table can be simplified so that they portray or emphasize only one trend, which improves student ability to recognize periodic trend patterns, which is a skill that is vital to metacognition and therefore, also code-switching (Rayner-Canham, 2000; Saecker, 2009; Schultz, 2005). By extension, Marais and Jordaan's (2000) research supports the simplification of the Periodic table under the logic that elimination of unnecessary symbols or information eases cognitive burden. Additionally, the act of reorganizing graphic organizers is a reflective task, which has educational and linguistic benefits, such as improving code-switching skills, which are detailed further in the last category of individual strategies (Taskin and Bernholt, 2014).
**Visual Representation of Abstract Concepts**

Strategies that classify as Visual Representation of Abstract Concepts include any instructional activities that feature visual or physical models, such as molecular models, kinesthetic activities, laboratory demonstrations and online simulations, for instruction that promotes student comprehension of abstract concepts. Activities with analogies are categorized here if they are not analyzed for limitations; Allegory analysis falls under Reflective Tasks regarding Abstract Concepts below. Titles of specific strategies are listed by module below.

*Module #1*: Accurate or Precise Horseshoe Throw, Essential Laboratory Equipment Posters, Laboratory Treasure Hunt, Scales with Whales  
*Module #2*: Periodic Table Seating Tickets  
*Module #3*: Electron Orbital Visualization, Excited Electron Basketball  
*Module #4*: Appearances can be Decieving!, Using Molecular Models to Highlight Bonds, Resonance Visualized  
*Module #5*: Using Molecular Models to show Electron "Ownership",  
*Module #6*: Pictoral Equations, The Elements go to Prom,

Similar to graphic organizers, the use of visual representations builds conceptual links between parallel representations of abstract concepts with the added benefit of easing cognitive load by eliminating excess linguistic symbols (Marais and Jordaan, 2000). Visual depictions of vocabulary words is a strategy commonly used in bilingual classrooms, which has also been successfully used in chemistry classrooms (Hanes, 2004). Hanes (2004) asserts that visual supports are specialized resources that support code-switching skills in both chemistry and bilingual students. Visual support can be used for singular vocabulary words or graphic organizers can be supplemented with multiple images, such as Bolmgren's (1995) addition of atomic depictions to the Periodic Table. While kinesthetic demonstrations and online simulations have not been researched in regards to chemical language, this author asserts that those activities also promote the creation of conceptual links for abstract concepts. Perhaps the most important conceptual link that visualizations can support is student understanding of
chemical phenomena from macroscale to submicroscale perspectives, which is traditionally done through laboratory demonstrations, but applicable to other visual forms as well (Jacob, 2001).

*Creative Expression of Abstract Concepts*

Strategies that classify as Creative Expression of Abstract Concepts include any instructional activities that feature structured guidance for discourse, reading and writing skills, such as conversational modeling, creative writing challenges, and other narratives, for instruction that promotes student comprehension of abstract concepts and communication for chemical fluency. Titles of specific strategies are listed by module below.

*Module #1:* Definitions Debate,
*Module #2:* Turning Lead into Gold Creative Writing,
*Module #3:* Conversations on Colloquial Misuses, "Electron"-ic Battleship,
*Module #4:* Elemental Personalities and Behaviors, Octet Rule-Breakers!
*Module #5:* Foolish Formulas,
*Module #6:* Narrative of a Chemist,

The primary educational goal that is supported by the use of creative expression activities is the development of chemical fluency with a classroom environment similar to bilingual immersion approaches (Reingold, 2005). Any opportunity for students to focus on chemical language in conversation, reading or writing improves their competency within the language (Reingold, 2005). Taskin and Bernholt (2014) indicated that student are able to communicate with greater competency and freedom when provided with a linguistic structural pattern, which can provide a guiding template for peer-to-peer dialogue.

Other authors have also described the benefits of chemistry teachers scaffolding metacognitive strategies for discourse and reading, however writing can also benefit from similar supports (Lapp, Fisher, and Grant, 2008; Warfa, Roehrig, Schneider and Nyachwaya, 2014).
Both Flores and Smith (2013) and Hanes (2004) encourage educators to provide students with templates for scientific writing support, which promote academic writing and code-switching skills.

Providing reading opportunities also improves chemical fluency, and is a strategy adopted by both Bretz and Meinwald (2002) with integrated case studies and Phillips and Norris (2009) with adapted primary literature. Additionally, activities commonly found in foreign language laboratories, such as guided discourse and multi-culturally themed readings can create chemistry cultural relevance for students, which promotes student inclusion, motivation and engagement (Markow 1988).

**Reflective Tasks regarding Abstract Concepts**

Strategies that classify as Reflective Tasks regarding Abstract Concepts include any instructional activities that feature the use of self-reflection after interactive exploration, designing analogies or mnemonic devices, or intuition-focused brain teasers, for instruction that promotes student comprehension of abstract concepts and self-improvement through metacognition. Titles of specific strategies are listed by module below.

*Module #1:* Calibration Comparison, Science-worthy Senses, Turning Definition Conflicts into Clues, Going Against the Grain - Changing Intuition,
*Module #2:* Relating to Relative Mass, Recognizing Limits of Analogies, Endless Analogies
*Module #3:* Magnets! How do they work?, The Electron Apartments at Energy Villa,
*Module #4:* Bond Strength versus Bond Energy,
*Module #5:* The Secret Formula,
*Module #6:* Is that really Organic?

The strategies in this category all include at least one approach from a previous category with one crucial extension: the implementation of reflective thinking. Taskin and Bernholt (2014) have championed the strategy of reflective tasks in regards to fostering chemical fluency.
They argue that reflective thinking with communication improves both conceptual understanding and linguistic competency (Taskin and Bernhold, 2014). One of their suggested methods to include reflective thinking within chemical fluency strategies is to allow students to design their preferred representations of the abstract concepts in question (Taskin and Bernhold, 2014). Additionally, Taskin and Bernhold (2014) suggest that educators should encourage students to speculate on the nature of existing chemical representations. Further, allowing students to share their ideas regarding chemical language fosters chemistry cultural relevance and therefore, student engagement (Markow, 1988).
Module Design

This project presents six language modules associated with the first six units in chemistry, which are typical unit divisions for Regents chemistry curricula in upstate New York. Each module features an overview, targeted learning objectives, a condensed content outline, detailed instructional strategies, suggested instructional materials and relevant research. Each module also has associated etymology, symbol and vocabulary glossaries as well as supplemental materials provided for certain instructional strategies.

The overview of each module describes the language needs of each unit by highlighting how said language needs relate to the foundational linguistic analogy of this project. Further, the module overview also highlights how the language needs addressed in each module prepare students for future learning and chemical language acquisition in following units.

The learning objective section of each module highlights the primary learning goal and also lists specific learning objectives that are situation-based, measurable and relevant to chemical language acquisition.

The content outline is divided into three parts: knowledge, skills and values. The knowledge portion lists the etymological stems, symbols and vocabulary terms that are addressed in the unit. The skills section lists general abilities that students need to succeed in that unit, which are also the foundations of the learning objectives in the previous section. The values section highlights an underlying idea about chemical language, which is supported by the module as a whole, but can also be specifically emphasized by the educator during the implementation of relevant instructional strategies.

The instructional strategies within the modules include learning activities, assessments and other supports that are all tailored to the specific language needs of each unit. Each strategy
section is divided into multiple challenges: Differentiation of related concepts, Differentiation of scientific and colloquial meanings, and each generic skill listed in the content outline. For the differentiation challenges, at least one learning strategy is provided for each vocabulary term and multiple strategies are provided for each skill challenge. All instructional strategies are modifications of research-supported bilingual and linguistic educational methods, which have been adapted to specifically promote the development of chemical language skills. Provided strategies in these modules include various forms of translation supports from bilingual education, literacy supports such as reading comprehension strategies using analytical etymology and conversational supports, such as modeling metacognitive behavior and discourse.

The instructional materials section lists supporting documents and specialized resources that are associated with the various instructional strategies divided into four sections: Regents-Specific, Online Tools, Glossaries and Other Materials.

The relevant research section lists citations of peer-reviewed articles that support the strategies of chemical language acquisition.
Suggested Use

The modules of this project have been designed to particularly support Regents Chemistry curricula in upstate New York, however are adaptable to other chemistry curricula due to their suggested "a la carte" implementation. Any educator can pick and choose from the provided instructional strategies to support their specific curriculum and teaching methods within their provided resources.

Adjustments for Curricular Differences:

For curricula that follow the same content pattern of units with the 'energy/atom-first' approach, differences should be minimal and easily adjusted for. Educators can simply ignore strategies for any vocabulary terms or skills that are not addressed within their curriculum. For vocabulary terms or skills that are not addressed within the modules, strategies parallel to this module's methods can be used. For example, most scientific words have distinct etymological roots, which educators can research and present to their students with the same metacognitive modeling approach as described here. Additionally, the provided glossaries can be expanded with terms, symbols and etymological roots specific to other's curricula.

For curricula that follow a different pattern of units, significant adjustments are necessary however the same approach is still applicable. In fact, the linguistic approach of this project can be broadened and applied to all sciences. To apply this linguistic approach to other curricular patterns, educators will need to analyze and identify the chemical language needs within their units. For example, a curriculum that starts with heavy focus on matter and phase changes (gases, liquids & solids) would have resource navigation skills, calculation symbol recognition and decoding/encoding skills for diagrams as their main chemical language needs. Therefore,
that unit would require a symbol glossary, metacognition modeling for reading diagrams and support for use of the Regents reference packets. Supports for each of those skills are all provided within various sections of this project's modules. Thus, an educator can extract the relevant supports from the various sections of these modules, adjust the strategies as needed and apply them to their curriculum.

Adjustments for Teaching Method Differences:

Even if following the same 'energy/atom-first' organization of units, all educators have differences approaches within their classroom. Regardless of whether an educator favors inquiry, direct instruction or other classroom models, the diversity of instructional strategies within this project ensure that at least some strategies will be compatible for every classroom.

Additionally, there is also the question of when to implement the provided instructional strategies within a lesson or unit to ensure the greatest positive impact on learning. It is the author's suggestion that the instructional strategies be applied preemptively whenever possible. Skills that are broadly applicable, such as resource navigation skills for the symbol glossary or metacognition modeling for etymological analysis, are ideally implemented at the very beginning of each unit. However, more specific skills, such as drawing chemical structures or decoding formulas would be ideally implemented at the beginning of the relevant lesson, wherever that may fall within the unit. The reasoning for this front-loading strategy is detailed further in the rationale, but can be summarized as thus: Teaching language needs first minimizes the cognitive load during content learning. In other words, it is easier for students to learn content, when they already have acquired the language skills, instead of learning content and language simultaneously.
Adjustments for Provided Resource Differences:

All educators have limitations regarding the educational resources that they have available in their classrooms. Therefore, the strategies in these modules have all been designed to be implementable in any school, no matter the differences in funding or learning environment. Any experiment-based activities use 'kitchen chemistry' for schools that have limited access to laboratory equipment, however the provided experiments can be replaced with more traditional chemistry experiments for schools with well-equipped learning laboratories. Visual activities favor low-technology strategies, with some high-technology alternatives for schools that have greater access to computers. All interactive learning strategies are either discourse, kinesthetic or paper-based in order to be inclusive and accessible to all classrooms.

Extrapolations for Other Units:

The six language modules of this project only cover the first six units of the 'energy/atom-first' Regents chemistry curriculum, however they lay the foundational of all chemical language needs in future units. All future units either require repetition or extrapolations of the strategies provided in the six modules. Units such as solutions, phase changes, thermodynamics, kinetics and equilibrium have resource navigations skills as their primary language need. Therefore, strategies used for etymological analysis and decoding & encoding supports from various modules are applicable and adaptable. The acid & base, nuclear and redox reaction units can be supported with strategies recycled from Module #6 for basic reactions. The nomenclature language needs in the organic chemistry unit can be supported with
the same or parallel strategies as Module #5 for naming simple compounds and decoding and encoding molecular formulas.

Ultimately, educators can apply the same process as outlined above for different unit divisions under adjustments for curricular differences. The educators will need to analyze and identify the chemical language needs within the following units, extract the relevant supports from the various sections of these modules, adjust the strategies as needed and apply them to the succeeding units.
Module Kit #1

College at Brockport, Department of Education & Human Development
Linguistic Strategies for Chemistry - Module #1
Designed by Genevieve Criss

Associated Chemistry Unit: Unit #1: Introduction to Chemistry
Unit Subject or Content area: Nature of Science, Energy & Matter, Scientific Notation
Module Title: Supporting Linguistic Foundations of Basic Concepts & Building Resource

<table>
<thead>
<tr>
<th>Navigation Skills</th>
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Module Overview: Provide a narrative that explains what language needs this module supports and why it is relevant?

The first unit of any subject proves a crucial time to establish the foundation for all future learning.

First, central vocabulary terms are presented, which must be mastered by students in order to develop further learning on related concepts. Students can demonstrate authentic understanding of scientific terms by communicating their definitions in both scientific and colloquial language, which requires that students learn how to translate or decode between scientific and colloquial language. Unfortunately, some terms do not have a 'direct' translation to colloquial language, which instead requires that students gain a more contextual or intuitive understanding, which can be promoted with visual supports and demonstrations. Educators must also be wary of scientific terms that have a different meaning in colloquial language, and must explicitly demonstrate the differences and the different contexts in which they are used.

Second, students must be taught how to use instructional tools that support their own language acquisition skills and aid their conceptual understanding. This primarily refers to the Regents Reference Packet, which students must be able to navigate to successfully solve chemistry problems. However, it also refers to the additional support glossary, such as the specialized vocabulary glossary, the etymological and symbol glossary.

Third, students should recognize that chemistry is a language. This perspective first makes complex chemistry seem achievable, by demonstrating that seemingly impossible texts can be broken down into surmountable challenges through metacognition, decoding or translation. Second, it gives students an empowering tool that they can use to promote and motivate their own learning. Third, it allows for better communication with all parties in the chemistry classroom. Students can engage in dialogue more readily with the teacher, their classmates or themselves through the medium of chemical language in order to learn chemical concepts.

Module Objective(s): Develop an objective statement that aligns with the language needs and uses observable and measurable goals.

The primary goal of this module is to build the foundation of language acquisition skills needed for students to be able to comprehend and communicate chemistry concepts. Specific objectives are:

- When faced with a novel scientific term or symbol, students will be able to identify or define the term through the use of the specialized scientific concepts vocabulary & symbols glossary.
- When faced with a novel scientific term, students will be able to estimate or provide a rudimentary definition of the term by analyzing the etymological stems.
- When asked to define a scientific term or to express a relationship between two terms, students should be able to provide answers in both scientific and colloquial language to demonstrate authentic understanding.
- When in a laboratory settings, students should be able to identify the name and use of basic chemistry equipment (may be with or without glossary support).
When asked to convert units, students should be able to utilize Table C of the Regents Reference Packet to successfully calculate the answer.

When faced with a challenging scientific text, students should be able to ask for specific linguistic help, which demonstrates their recognition that science is a language.

Content Outline

1) Knowledge
   • Etymology: Morphemes used in basic scientific terminology & unit prefixes (Table C)
   • Symbols: Mathematical Symbols used in scientific notation
   • Vocabulary (Practical): Beaker (Griffin/Low-form, Berzelius/High-form, Crystallizer/Flat-form, Pitcher), Flask (Erlenmeyer/Conical, Florence/Round-Bottomed/Boiling, Volumetric), Hot Plate, Graduated Cylinder, Crucible, Tongs, Chemical, Stir Rod, Bunsen Burner, Tripod, Test Tube, Pipette, Mortar & Pestle, Scoopula, Ring Stand, O-ring, Wire Gauze, Clamp, Triangle, Funnel, Watch Glass

2) Skills
   • Ability to... Navigate and apply information in Table C to convert units
   • Ability to... Navigate online resources, such as the symbol, etymology & vocabulary glossary
   • Ability to... Explain concepts (and express relationships between concepts) in both colloquial and scientific language
   • Ability to... Identify laboratory equipment by name and function

3) Values
   • Demonstrate... Recognition and Importance of the language of Chemistry

Activities, Assessments, Instructional Strategies & Supports

1) Challenge: Differentiation of Paired/Related Concepts
   Applicable to: Matter vs Energy, Mass vs Weight, Chemical vs Physical (Change), Precision vs Accuracy, Potential vs Kinetic (Energy), Exothermic vs Endothermic (Reaction), All unit prefixes from Table C
   Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision vs Accuracy</td>
<td>Accurate or Precise Horseshoe Throw</td>
<td>Using a game of horseshoes (or similar target game such as darts), demonstrate four rounds that each show 3 shots that are 1) both accurate &amp; precise, 2) accurate but not precise, 3) precise but not accurate, 4) neither precise nor accurate. If a physical game is not possible, a video can suffice. If possible, hang a poster with the four targets (See Image #1 in Supplemental Materials Appendix for Module #1).</td>
</tr>
<tr>
<td>Precision vs Accuracy</td>
<td>Calibration Comparison</td>
<td>Divide the class into multiple groups (a multiple of 4, say 8 or 12) and give each group on of the four rulers (See Image #2 in Supplemental Materials Appendix for Module #1). Explain to the students that these rulers measure a new unit of length: the blurple. Give the groups a few identical items to measure (ex: a drinking straw, a plastic knife, a styrofoam cup). Have each group write</td>
</tr>
</tbody>
</table>
their findings on a chart on the board. Ask the class to compare and contrast all the findings, and encourage discussion of why the numbers are different. Have the different groups compare their rulers and ask students to hypothesize how accuracy and precision is affected by each type of the four rulers. Students should eventually come to the understanding that the ruler must be correctly calibrated for accuracy and have more markings (greater sensitivity) for precision. This activity can also be adjusted for measuring amounts of liquid using differently calibrated beakers & flasks.

| Potential vs Kinetic, Exo... vs Endothermic, Table C, etc. | Analysis of Morphemes used in Scientific Terminology | Using the etymological glossary as a reference, explicitly demonstrate the metacognitive process to analyze the morphemes within foreign words to ascertain their meaning. This process is also known as decoding. (See Module-Specific Glossary #1 & #2 in Supplemental Materials Appendix for Module #1) |
| Mass vs Weight, Matter vs Energy | Definitions Debate | Arrange students in pairs and give them each a set of slips of paper with the four scientific terms of mass, weight, matter and energy, at least one scientific definition of each term, at least one colloquial definition of each term and if possible a definition of each term that falls somewhere between scientific and colloquial language. Ideally, the different definitions should describe the terms from the perspectives of macroscale and submicroscale, however symbolic definitions can also be used. Students should work together to match the various definitions to the four scientific terms in question, and also compare/contrast the four definitions for further clarity and understanding. Model scientific discourse to support student debate skills as needed. (See Worksheet #1 in Supplemental Materials Appendix for Module #1). |
| Matter vs Energy, Chemical vs Physical Change | Science-worthy Senses | Challenge the students to work in pairs to find multiple forms on energy present in the classroom using their physical senses. They should be able to find heat, light and sound (using their sight, hearing & touch). Ask the students to compare and contrast the senses abilities to detect energy versus matter. Model scientific discourse to support student communication skills as needed. Summarize their findings in a venn diagram on the board (See Image #3 in Supplemental Materials Appendix for Module #1). This activity can also be adjusted to demonstrate the difference between chemical and physical changes. Provide students with multiple stations that either demonstrate a chemical or physical reaction. Challenge the students to compare and contrast what senses they used to observe the chemical changes or physical changes taking place. |
| Potential versus Kinetic Energy in Toys | Types of Energy in Toys | Arrange students into groups of four and provide them with a rubber band, a slinky, silly putty, a bouncy ball and a graphic organizer. Challenge the students to demonstrate at least one example of potential energy and kinetic energy with each of the toys. Have students discuss amongst their groups whether their examples used gravitational or mechanical energy (or other energy forms) and how they know their examples were kinetic or potential energy. |
2) Challenge: Differentiation of Scientific & Colloquial Meanings
Applicable to: Precipitate,
Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitate,</td>
<td>Turning Definition</td>
<td>Provide or encourage students to develop their own mnemonic devices that stem from the colloquial definitions to help them remember the scientific definitions. Ex: Colloquially, precipitate means 'rain' or 'snow.' Scientifically, it means a solid that &quot;rains&quot; from out a solution after a reaction takes place. Alternatively, the formation of a precipitate looks like a shaken snow globe. (See Module-Specific Glossary #2 in Supplemental Materials Appendix for Module #1;</td>
</tr>
<tr>
<td></td>
<td>Conflicts into Clues</td>
<td></td>
</tr>
</tbody>
</table>

3) Challenge: Identification of Laboratory Equipment
Applicable to: All practical vocabulary listed above
Possible Activities

- Essential Laboratory Equipment Poster - Place poster in laboratory area that displays labeled pictures of common laboratory equipment (See Image#4 in Supplemental Materials Appendix for Module #1)
- Laboratory Treasure Hunt - Provide each student a worksheet that has a table with 3 categories to fill out: picture, name & use. Students will need to identify each piece of equipment and it's function, and can be asked to draw a picture of it. This activity can be used for introductory learning or assessment. (See Worksheet #2 in Supplemental Materials Appendix for Module #1)

4) Challenge: Convert Units from Table C
Applicable to: All units in table C
Possible Activities

- Going against the Grain; Changing Intuition - Label four jars of various sizes (from jelly jar size to an 8 gallon drum with wheat, rice, sand and salt. Measure out wheat seed, rice, sand and salt so that that each jar has one millions grains of each substance: 1 million grains of salt is approximately 1/6 cup, coarse sand is 1/2 cup, rice is 8 cups, wheat seeds are 8 gallons (Note: Due to the large size of wheat seed needed, this substance can be excluded if desired). Allow the students to weigh the jars as well as one grain of each substance (provide mass of empty containers) and to try to calculate how many grains are in each container. Students should come to the realization that each container has approximately 1 million grains. Ask the students to calculate how many grains would be in only one cup for each substance. Then ask the students to use conversions for one of the four substances to find it's measurements in decigrams, centigrams, milligrams, and kilograms. Students may work in groups. Students that need more practice can covert units for more than one substance. (See Worksheet #3 in Supplemental Materials Appendix for Module #1)
- Scales with Whales - Provide visual images alongside with units to demonstrate their size, whether humongous or tiny, to support intuitive understanding of scales. For example with meters: Provide a picture of a whale seen one milimeter away (blurry gray), 1 centimeter away (wrinkled skin) 1 meter away (see whale looking big), 1 kilometer away (tiny whale in the distance).
- Unit Conversions Decoded - On the students Regents Reference packet shown them how to redraw Table C or allow them to develop their own prefered chart with Table C information. The redrawn table should clearly demonstrate how to set up conversion equations via dimensional analysis. As needed, provide the students with extra support such as the student tips for Regents References packet as well as the etymological glossary for unit prefixes (See Module-Specific Glossary #1 in Supplemental Materials Appendix for Module #1; See Etymology Glossary & Regents Reference Packet Support #1 in Supplemental Materials Appendix for all Modules). See example of adjusted table below.
<table>
<thead>
<tr>
<th>Base unit</th>
<th>Equals</th>
<th>Prefix</th>
<th>Base unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 10^3$</td>
<td>Meters</td>
<td>=</td>
<td>1</td>
</tr>
</tbody>
</table>

Therefore

<table>
<thead>
<tr>
<th>Base unit</th>
<th>Equals</th>
<th>Prefix</th>
<th>Base unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Meter</td>
<td>=</td>
<td>$1 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

5) Challenge: Recognize foreign mathematical or chemical symbols
   Applicable to: $\Delta H$, $\rightarrow$, Scientific Notation, Conversion symbols, etc.
   Possible Activities
   - Side Note Basic Symbols Key: In the student notes packets, place a glossary box in the margins that defines the new symbols. For example, in scientific notation, the mantissa and exponent should be highlighted and defined. Demonstrating where heat lies in a reaction equation (before or after the arrow) clarifies whether the reaction is exo or endothermic. Alternatively, an entire symbol glossary can be provided. (See Module-Specific Glossary #1 in Supplemental Materials Appendix for Module #1; See Etymology Glossary & Regents Reference Packet Support #1 in Supplemental Materials Appendix for all Modules).

**Instructional Resources and Materials to engage students in learning:**

1) Module Specific: See Supplemental Materials Appendix for Module #1 Below
   Images
   - **Image #1:** Targets for Accurate or Precise Horseshoe Throw
   - **Image #2:** Four Rulers for Calibration Comparison
   - **Image #3:** Venn Diagram for Science-Worthy Senses
   - **Image #4:** Essential Laboratory Equipment Poster
   Worksheets
   - **Worksheet #1:** Term and Definition Slips Worksheet for Definition Debate
   - **Worksheet #2:** Laboratory Equipment ID Worksheet for Laboratory Treasure Hunt
   - **Worksheet #3:** Weights and Calculations Worksheet for Going Against the Grain
   Module Specific Glossaries
   - **Glossary #1:** Etymology of basic scientific terminology & unit prefixes
   - **Glossary #2:** Vocabulary of basic scientific terminology
   - **Glossary #3:** Symbols of basic math and chemistry

2) General: See Supplemental Materials Appendix for all Modules
   Glossaries
   - **Glossary #1a:** Etymology Glossary for Scientific Terminology & Concepts
   - **Glossary #2:** Vocabulary Glossary for Scientific Concepts and Terminology
   - **Glossary #3:** Symbol Glossary for Mathematic and Chemical Symbols
   Regents Reference Tables Supports
   - **Regents Reference Table Support #1:** Links for Navigating Regents Reference Tables
Relevant theories and/or research best practices:

What theories and scholarly sources ground your decisions about the learning tasks?

1) General Theories
   - Linguistic Etymology, Specialized Glossaries, Mnemonic Devices, Visual supports, Metacognition, Code-switching & Translation

2) Research Articles

   Etymology

   Contradictory Definitions (Colloquial vs Scientific Language)

   Metacognitive and other Linguistic Supports

   Specialized Glossaries

   Code-Switching
Appendix of Supplemental Materials for Module Kit #1

**Image #1:** Targets for Accurate or Precise Horseshoe Throw

![Image of targets showing accuracy and precision](image1)

**Image #2:** Four Rulers for Calibration Comparison

- **Ruler A:** Correct Calibration for Accuracy and Greater Markings for Precision
  
  ![Ruler A](image2a)

- **Ruler B:** Incorrect Calibration for Inaccuracy and Greater Markings for Precision
  
  ![Ruler B](image2b)

- **Ruler C:** Correct Calibration for Accuracy and Fewer Markings for Imprecision
  
  ![Ruler C](image2c)

- **Ruler D:** Incorrect Calibration for Inaccuracy and Fewer Markings for Imprecision
  
  ![Ruler D](image2d)
Image #3: Venn Diagram for Science-Worthy Senses

ENERGY

Hearing & Sight

MATTER

Touch & Taste & Smell

Can be sensed with....

Image #4: Essential Laboratory Equipment Poster
**Worksheet #1: Term and Definition Slips Worksheet for Definition Debate**

**Definition Debate**

**Instructions:** Cut along the lines to separate the terms and given definitions. There are four terms, four scientific definitions, four colloquial definitions and four intermediate definitions. Assign three definitions (One scientific, one colloquial and one intermediate) to each term.

<table>
<thead>
<tr>
<th>Term</th>
<th>Scientific Definition</th>
<th>Colloquial Definition</th>
<th>Intermediate Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>A property of matter, which is a measure of the resistance to acceleration when force is applied</td>
<td>Any physical substance which occupies space and possesses mass.</td>
<td>The relative mass of a physical substance as it is related to the local gravitational pull</td>
</tr>
<tr>
<td>Matter</td>
<td>A property of objects which can be transferred to other objects or converted into other forms</td>
<td>The mass of a physical object is roughly dependant on the amount of atoms within that object</td>
<td>Any physical substance that is composed of atoms or molecules</td>
</tr>
<tr>
<td>Weight</td>
<td>The force of an object due to gravity</td>
<td>In some cases, the ability of a system to do work</td>
<td>The amount of stuff within a physical object</td>
</tr>
<tr>
<td>Energy</td>
<td>In some cases, the ability of a system to do work</td>
<td>The amount of stuff within a physical object</td>
<td>Any stuff that you can grab with your hand and move</td>
</tr>
<tr>
<td></td>
<td>The amount of stuff within a physical object</td>
<td>Any stuff that you can grab with your hand and move</td>
<td>How heavy an object feels when you try to lift it</td>
</tr>
<tr>
<td></td>
<td>Forms of power, such as light, heat and electricity</td>
<td>Forms of power, such as light, heat and electricity</td>
<td>Forms of power, such as light, heat and electricity</td>
</tr>
</tbody>
</table>
**Answer Key**

*Note: Terms & associated definitions indicated by color*

<table>
<thead>
<tr>
<th>Term</th>
<th>Scientific Definition</th>
<th>Colloquial Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>A property of matter, which is a measure of the resistance to acceleration when force is applied</td>
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<td>Matter</td>
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</tr>
<tr>
<td>Weight</td>
<td>The relative mass of a physical substance as it is related to the local gravitational pull</td>
<td>How heavy an object feels when you try to lift it</td>
</tr>
<tr>
<td>Energy</td>
<td>A property of objects which can be transferred to other objects or converted into other forms</td>
<td>Forms of power, such as light, heat and electricity</td>
</tr>
</tbody>
</table>
Worksheet #2: Laboratory Equipment ID Worksheet for Laboratory Treasure Hunt

Name _______________________________________________

Go around the room and draw a picture of each piece of laboratory equipment, record its name, and determine what its used for (measuring, reaction vessel, other)

<table>
<thead>
<tr>
<th></th>
<th>Picture</th>
<th>Name</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Worksheet #3: Weights and Calculations Worksheet for Going Against the Grain

**Going Against the Grain: Changing Intuition**

**Instructions:** Your instructor will provide you with three or four jars of various sizes that are each filled with only wheat, rice, sand or salt. In Part A, you will weight each filled jar and one grain from each jar. The weight of the empty jars and how many cups of material are in each jar will be provided for you. Using the weight of one grain and total weight of the jar contents, calculate using dimensional analysis how many grains are in each container in Part B. Then calculate how many grains would be in only one cup of each substance. For extra credit, you may also use unit conversions to find the number of decigrains, centigrains and milligrains and kilograins for one of the four jars.

**Part A: Weigh your materials**

<table>
<thead>
<tr>
<th></th>
<th>Filled jar (g)</th>
<th>Empty Jar (g) - given</th>
<th>One grain (g)</th>
<th># Cups in jar - given</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part B: Show your work! Calculate the number of grains in...**

1. The Jar of Wheat

2. The Jar of Rice
3. The Jar of Sand

4. The Jar of Salt

**Part C:** Extra Credit! For one jar, convert the number of grains into...
1. Decigrains

2. Centigrains

3. Milligrains

4. Kilograins
**Answer Key**

**Note:** Tables outlining number of grains and cups for the four materials. Wheat seed may be excluded since it's jar of 1 million grains is very large (One bushel!)

<table>
<thead>
<tr>
<th>Grains of</th>
<th>Salt</th>
<th>Coarse sand</th>
<th>Rice</th>
<th>Wheat Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 million</td>
<td>1/6 cup (.167 cups)</td>
<td>1/2 cup</td>
<td>8 cups</td>
<td>128 cups</td>
</tr>
</tbody>
</table>

| 1 cup of | Salt 6 million Grains | Coarse Sand 2 million grains | Rice 1.25 million decigrains | Wheat Seed 7.8 million Milligrains |

<table>
<thead>
<tr>
<th>1/6 cup</th>
<th>Salt 1 million grains</th>
<th>Sand 1/3 million grains AKA ~3 million Decagrains</th>
<th>Rice 1/48 million grains AKA ~2 million Hectograins</th>
<th>Wheat 1/768 million grains AKA ~1 Kilogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 cup</td>
<td>3 million grains</td>
<td>1 million grains</td>
<td>1/16 million grains AKA ~6 million Hectograins</td>
<td>1/256 million Grains AKA ~4 Kilograms</td>
</tr>
<tr>
<td>8 cups</td>
<td>48 million grains AKA ~5 million decigrains</td>
<td>16 million grains AKA ~2 million decigrains</td>
<td>1 million grains</td>
<td>1/16 million grains AKA ~6 million Hectograins</td>
</tr>
<tr>
<td>128 cups</td>
<td>768 millions grains AKA ~8 million centigrains</td>
<td>256 million grains AKA ~3 million centigrains</td>
<td>16 million grains AKA ~2 million decigrains</td>
<td>1 million grains</td>
</tr>
</tbody>
</table>
Module-specific Glossary #1: Etymology of basic scientific terminology & unit prefixes

Etymological Glossary for Module #1

accur (Latin) To do with care  Ex: Accurate
ace See acc
acr See acc
acu See acc
al See ial
at See ate
ate (Latin) To act by [verb] or to be like [adjective]  Ex: Observation
centi (Latin) Hundred  Ex: Centimeter, Centigrad
chem (Latin) Transformation of matter  Ex: Chemistry, Chemical
cis (Latin) cut  Ex: Precise
cis (Latin) on the same side  Ex: Cis-isomer
deci (Latin) Ten  Ex: Decimal, Decimeter
decim See deci
dict (Latin) To say  Ex: Predict
ence (Latin) Having the quality or action of  Ex: Science
endo (Latin) In or to enter  Ex: Endothermic
ent (Latin) To be  Ex: Scientific, Kinetic
ery See ry
et See ent
exo (Latin) Out or to exit  Ex: Exothermic
ial (Latin) Related to  Ex: Potential
ic (Latin) Pertaining to  Ex: Chemical
ics See ic
if (Latin) Has characteristics of  Ex: Scientific
ion (Greek) To go  Ex: Ionic
ion (Latin) State or action of  Ex: Observation
ist (Latin) One who does  Ex: Chemist
ive See if
kilo (Greek) Thousand  Ex: Kilometer, Kilogram
kin (Greek) Movement  Ex: Kinetic
ly (Old German) Having the characteristics of  Ex: Accurately
ly (Old German) at the interval of
micro (Greek) small  Ex: Microscope
milli (Latin) One thousandth  Ex: Millimeter
nano (Greek) Dwarf  Ex: Nanometer
not (Latin) To know or to note  Ex: Notation
observ (Latin) To watch or heed  Ex: Observation
Examples of Etymological Analysis

<table>
<thead>
<tr>
<th>Word</th>
<th>Latin/Greek/Old French</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>phys</td>
<td>(Greek) Nature or life</td>
<td>Ex: Physical</td>
<td></td>
</tr>
<tr>
<td>pico</td>
<td>(Spanish) Little bit</td>
<td>Ex: Piconometer</td>
<td></td>
</tr>
<tr>
<td>pon</td>
<td>(Latin) To put</td>
<td>Ex: Exponent</td>
<td></td>
</tr>
<tr>
<td>potent</td>
<td>(Latin) Ability or power</td>
<td>Ex: Precipitate</td>
<td></td>
</tr>
<tr>
<td>pre</td>
<td>(Latin) Before</td>
<td>Ex: Precise, Predict</td>
<td></td>
</tr>
<tr>
<td>precipi</td>
<td>(Latin) Hurl down</td>
<td>Ex: Chemistry</td>
<td></td>
</tr>
<tr>
<td>ry</td>
<td>(Old French) Craft, group or place of [noun]</td>
<td>Ex: Microscope</td>
<td></td>
</tr>
<tr>
<td>sci</td>
<td>(Latin) To know or knowledge</td>
<td>Ex: Science, Scientific</td>
<td></td>
</tr>
<tr>
<td>scope</td>
<td>(Greek) To know or knowledge</td>
<td>Ex: Microscope</td>
<td></td>
</tr>
<tr>
<td>therm</td>
<td>(Greek) Heat</td>
<td>Ex: Exothermic, Endothermic</td>
<td></td>
</tr>
</tbody>
</table>

Accurate accru + ate To be done with care
Centimeter centi + meter One Hundredth of a Meter
Chemical chem + ic + al That which pertains to the transformation of matter
Chemist chem + ist One who transforms matter
Chemistry chem + ist + ry The craft of one who transforms matter
Decimal deci(m) +al Related to Tenths
Endothermic endo + therm + ic Pertaining to heat entering
Exponent ex + pon + ent (Number) to be put out (really, up!)
Exothermic exo + therm + ic Pertaining to heat exiting
Kilometer kilo + meter One Thousand Meters
Kinetic kin + et + ic Pertaining to be in motion
Microscope micro + scope (Tool) to view small (things)
Notation not + ate + ion The action of noting or knowing
Observation observ + ate + ion The act of watching
Physical phys + ic + al Related to nature or life
Potential potent + ial Related to power
Precipitate precipi + ate That which is hurled down
Precise pre + cis To cut (short)
Predict pre + dict To say before (it happens)
Science sci + ence The action of knowing
Scientific sci + ent + if + ic Pertaining to the action of knowing
Module-specific Glossary #2: Vocabulary of basic scientific terminology

Vocabulary Glossary for Module #1

**Accuracy**
The correctness of a measurement based on its comparison to the true or accepted value
(Translation) How close a measurement is to the true value.

**Chemical**
Relating to chemistry

**Chemical (substance)**
A form of matter that has a fixed composition and properties.
(Translation) Substances such as elements, compounds and molecules.

**Chemical (change)**
A reaction of a chemical substance or substances that results in the dissociation, recombination or rearrangement of atoms.
(Translation) A change that produces a new substance

**Chemistry**
The branch of science that investigates the structure, properties, interactions and transformations of matter.
(Translation) The study of matter and how it changes.

**Endothermic**
A process that absorbs heat energy

**Energy**
A property of objects, which can be transferred to other objects or converted into other forms
(Translation) Forms of power, such as light, heat and electricity, which often have the capacity to do work

**Exothermic**
A process that releases heat energy

**Heat**
A form of energy that is proportional to the amount of molecular motion
(Translation) A form of energy that is measured by temperature

**Kinetic**
Related to the rate of reaction

**Kinetic (energy)**
The energy that an object possesses, because of its motion

**Mass**
A property of matter, which is a measure of the resistance to acceleration when force is applied
(Translation) A property of matter, which is roughly dependent on the amount of atoms within a physical object

**Matter**
Any physical substance, which occupied space and possesses mass
(Translation) Any physical substance, which is composed of atoms or molecules, that you can touch

Observation
The act of physically measuring the properties of a system

Physical
Related to matter
Note: Refer to Matter

Physical (change)
A change that only alters the appearance of a substance, such as switching physical states, but maintains identity of a substance, because the atomic structure is not rearranged
(Translation) A change in appearance that does not transform one substance into another
Note: Compare to Chemical (change)

Potential (energy)
The energy that an object possesses, because of its position, composition or condition
Note: Compare to Potential (energy)

Precipitate
An insoluble solid that separates from a solution, which is the product of a chemical reaction between compounds or ions in the solution

Precision
The correctness of a measurement or series of measurements based on the reproducibility of the measurement(s)
(Translation) How close a measurement is to repeated measurement of the same thing.

Temperature
A measure of the intensity of heat
Note: Refer to Heat

Weight
The relative mass of a physical substance as it is related to the local gravitational pull
(Translation) The force of an object due to gravity, which is how heavy an object feels when you try to lift it
Note: Compare to Mass
Module-specific Glossary #3: Symbols of basic math and chemistry

Symbol Glossary for Module #1

Singular Symbols

Δ Change or sometimes heat, when written in a chemical equation. Change does not indicate a chemical change, but rather a change in the amount of something

→ Chemical Change (indicates a chemical reaction)

(g) gaseous state

(l) liquid state

(s) solid state

E Energy

H Heat

Symbol Combinations

ΔE Change of the amount of energy

ΔH Change of the amount of heat

ΔH → Indicates an endothermic reaction

→ ΔH Indicates an exothermic reaction

Types of Symbol Notation

Decimal Notation The numerical system typically used in pure mathematics, which uses integers and a decimal point

(Looks like) 100.05

Scientific Notation The numerical system often used in chemistry, specifically for exceptionally large or tiny numbers, which uses powers of ten

(Looks like) \(1 \times 10^5\)

where the ________ is the...

Mantissa The real number, also called the significand

(Looks like) \(1 \times 10^5\)

Base The number that is going to be raised by the power

(The base is always 10 in scientific notation)

(Looks like) \(1 \times 10^5\)

Exponent The raised power as shown by the superscript
Significant Figures

The digits in a number (which can be in decimal or scientific notation) that are considered accurate. Said digits depend on the accuracy and reliability of the measuring device used.

(Looks like) $1 \times 10^5$
Module Kit #2

College at Brockport, Department of Education & Human Development
Linguistic Strategies for Chemistry - Module #2
Designed by Genevieve Criss

Associated Chemistry Unit:  Unit #2: The Atom
Unit Subject or Content area:  Atoms, Subatomic Particles, Ions, Isotopes, Atomic Models
Module Title:  Learning to Read the Chemical Alphabet: Elements & The Periodic Table

**Module Overview**

*Provide a narrative that explains what language needs this module supports and why it is relevant?*

The second unit of chemistry usually introduces the single most powerful linguistic and informational tool in chemistry: the periodic table. The Periodic table practically acts as the Rosetta stone of chemistry in that it is the most condensed version of the vital chemical information needed to speak the language of chemistry.

The central learning objective is for students to be able to 'read' the periodic table. The ability to extract vital information, or in other words, to decode chemical information from the periodic table is absolutely essential for students to succeed in chemistry. Students must be able to find the relevant information on the Periodic Table and recognize trends demonstrated by the table that determine chemical behavior.

When armed with the ability to read the Periodic Table, students can apply that information to encode other information, such as drawing atomic models or writing atomic symbols. However the ability to draw these representations also requires linguistic and heuristic support from the educator to ensure students' mastery of these skills.

This section is also a strategic point to introduce students to the 'dialects' of chemistry as they correlated to the three scales of chemistry, macroscale, submicroscale (or atomic) and symbolic. Parallel representation of these dialects and other supports will help build the foundation for student's ability to translate between the dialects of chemistry. Lastly, representation of how atomic models and therefore chemical language has evolved over time further adds to students' understanding that chemistry is a language.

**Module Objective(s):**

*Develop an objective statement that aligns with the language needs and uses observable and measurable goals.*

The primary goal of this module is to introduce the students to the Periodic Table and build the skills needed for them to decode relevant chemical information from it's massive database. Specific objectives are:

- When faced with the atomic symbol or model of a novel element, students will be able to identify the element and extract relevant information such as atomic number, mass number or number of subatomic particles with the use of the periodic table and Table S as needed.
- When challenged to draw the atomic symbol or model of a novel element, students will be able to correctly depict said symbol or model with the use of the periodic table and Table S as needed.
- When asked to identify a chemical trend on the periodic table, students should be able to explain that trend in both scientific and colloquial language to demonstrate authentic understanding.
- When faced with a novel scientific term, students will be able to estimate or provide a rudimentary definition of the term by analyzing the etymological stems.
- When asked to define a scientific term or to express a relationship between two terms, students should be able to provide answers in both scientific and colloquial language to demonstrate authentic understanding.
Content Outline

1) Knowledge
- Etymology: Atomic Morphemes & Elemental Etymology
- Symbols: Atomic Symbols, Elemental Symbols, Subatomic particles, Atomic Models,
- Vocabulary: Element, Atom, Subatomic Particle, Ion, Isotope, Proton, Neutron, Electron, Nucleus, Mass Number, Atomic Number, Atomic Mass, Charge, Orbit, Cloud,

2) Skills
- Ability to... Navigate and apply information from Table S & the Periodic Table
- Ability to... Decode and Encode Atomic Symbols & Atomic Models
- Ability to... Distinguish between Elements, and Isotopes and/or Ions of specific Elements

3) Values
- Demonstrate... Recognition of the Development of Chemical Language through Historical Models

Activities and Instructional Strategies

1) Challenge: Differentiation of Paired/Related Concepts
Applicable to: Element vs Atom, Mass Number vs Atomic Mass, Isotope vs Ion vs Atom, Proton vs Neutron vs Electron,

Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element vs Atom</td>
<td>Scalar Depictions of</td>
<td>Provide students with a blank graphic organizer that is divided into Element, &amp; Atom from top to bottom. Each section should &quot;zoom&quot; in as you go down. For element part A, there should be two boxes provided in which students draw a mascroscale depiction of an element in each box. Next for part B, they should draw a submicroscale depiction of an element (a bunch of identical atoms, do not need to show subatomic particles). Last, in the symbol section, part C, students should draw a model of one atom for each of the two elements using whatever model they prefer. Said model should show protons, neutrons and electrons, but need not necessarily show the correct number of subatomic particles. Other graphic organizers, such as the Frayer model, can also be used. (See Worksheet #1 in Supplemental Materials Appendix for Module #2)</td>
</tr>
<tr>
<td>Mass Number vs Atomic Mass</td>
<td>Relating to Relative</td>
<td>Explain to the group that each student will be considered one atom of &quot;student&quot; and that the mass of &quot;student&quot; is based upon how many books are in their backpack. Have a volunteer tally on the board how many books each student has and help the students organize that data into a frequency chart in order to calculate the relative amount of books.</td>
</tr>
</tbody>
</table>
Highlight the analogies between atomic mass as the relative amount of books and the mass number as the amount of books one student (picked at random) has.

<table>
<thead>
<tr>
<th>Isotope vs Ion vs Atom</th>
<th>Turning Lead into Gold creative writing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Give students a sheet with the names, atomic numbers, atomic masses, and ratios of subatomic particles of lead, thallium, mercury and gold. Definitions of Isotope, ion &amp; atom should be provided and their relationships to one another highlighted in regards to radioactive decay. Ask students to write a few days of journal entries detailing the story of a lead atom spontaneously decaying into gold (from the perspective of the atom). Each story should use colloquial english, but have the ratios of subatomic particles and identify of the atom (lead, thallium, mercury or gold) clearly stated. Students should be able to simplify their stories into scientific language when spoken to individually by the teacher. Note that students can write their own creative story similar to the provided narrative, or students can be given a narrative with blanks to fill out. (See Worksheet #2 in Supplemental Materials Appendix for Module #2)</td>
</tr>
</tbody>
</table>

| Proton vs Neutron vs Electron vs Ion vs Atom, Analysis of Atomic Morphemes and Elemental Etymology | Using the etymological glossary as a reference, explicitly demonstrate the metacognitive process to analyze the morphemes within foreign words to ascertain their meaning. This process is also known as decoding. (See Glossary #1 and #2 in Supplemental Materials Appendix for Module #2; See Etymology Glossary in Supplemental Materials Appendix for all Modules) |

2) Challenge: Differentiation of Scientific & Colloquial Meanings

**Applicable to:** Element, Orbit, Cloud

**Possible Activities**

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit, Cloud</td>
<td>Recognizing Limits of Analogies</td>
<td>Have students work in pairs to compare the two definitions of a term from a colloquial dictionary and a scientific glossary to analyze the similarities and differences in meaning. Place special emphasis on having the students identify and explain to each other where the colloquial definition &quot;breaks down&quot; as an accurate description of the scientific concept. (See Glossary #2 in Supplemental Materials Appendix for Module #2; See Vocabulary Glossary in Supplemental Materials Appendix for all Modules)</td>
</tr>
<tr>
<td>Element</td>
<td>Alchemic Etymology</td>
<td>Explain the etymologic history of the alchemically-inspired word element with particular focus on how the meaning and understanding of the word element has changed over time as language adjusted along with the growing knowledge of</td>
</tr>
</tbody>
</table>
3) Challenge: Decoding (Unpacking) of the Periodic Table & Table S

Applicable to: All Elements

Possible Activities

- Simplified Versions of the Periodic Table - Present and have students use a version of the Periodic Table that only depicts one (or maybe two) trend/s. For example, students can organize buttons of different sizes to represent atomic radius trends in elements. Certain interactive Periodic Tables online can be simplified to demonstrate only one trend at a time. (See Images #1 through #7 in Supplemental Materials Appendix for Module #2; For link to Interactive Periodic Table, See Regents Reference Table Support #2 in Supplemental Materials Appendix for All Modules)

- Emphasized Trend Versions of the Periodic Table - 3D Periodic Tables can be erected in a way that have moveable pieces to highlight different rows & columns in order to focus on specific areas and thus trends. (See Images #8 in Supplemental Materials Appendix for Module #2)

- Color-coding the Periodic Table and Table S - On the students Regents Reference packet show students how to mark or highlight Table S and the periodic Table in ways that support their use of the table by highlighting specific information or trends. For example, have students color the areas within the periodic table to indicate metals, non-metals and metalloids; the groups and periods; or to highlight atomic trends as described in simplified or emphasized versions of the periodic table above. Students are encouraged to develop their own preferred marking systems, which should support student navigation and application of the Periodic Table or Table S. As needed, provide the students with extra support such as the student tips for Regents References packet (See Regents Reference Tips Packet in Supplemental Materials for all Modules).

4) Challenge: Encoding (Repacking) of the Periodic Table

Applicable to: All Elements

Possible Activities

- Alien Periodic Table - This activity asks students to determine the identity of the first 18 elements, when given "translated" descriptions and their names in an alien language (each alien element corresponds to an earth element). By organizing these elements to fit into the periodic table, students can gain better understanding towards how the periodic table is organized and also an intuitive understanding of how chemical concepts span across languages. (See Worksheet #3 in Supplemental Materials for Module #2)

- Periodic Table Seating Tickets AKA The Elements Attend a Concert - In this activity, students represent individual elements and must find their assigned seat using information from their concert ticket. Rearrange the desks so that they are arranged in the same format of the first three rows of the periodic table. Give each students a ticket with the atomic symbol of one element and are encourage to speak to one another for help finding their seating assignment.

- Alternative Depictions of Periodic Tables: Demonstrate to students how simplified versions of the periodic table can be recombined to form alternative depictions of the Periodic Table. Alternative Depictions of the Periodic Table can also be provided and students given the opportunities to ascertain how they evolved from the original periodic table. (See Images for examples of alternative periodic tables in supplemental materials)
5) Challenge: Decode & Encode Atomic Models  
Applicable to: All atomic models and subatomic particle depictions  
Possible Activities  
  • Atomic History Graphic Organizer: While atomic models have changed drastically throughout scientific history, they all represent the same concept, just using different dialects of chemical language that were dependent on the available knowledge of that time period. Therefore to demonstrate their connection, provide a graphic organizer with the atomic models organized by history, particles depicted, and scientific implications. To add a creative component, students can also be encouraged to draw their own version of the atomic models based on a hypothetical future scientific discovery, and share their creation with a conversational partner. (See Worksheet #4 in Supplemental Materials Appendix for Module #2)  
  • Side Note Atomic Model Key: Next to atomic models, place a glossary box in the margins that defines the new symbols. Specifically, each subatomic particle should be labeled. Further, comparisons of different atomic models with labeled symbols can be provided. (See Glossary #3 in Supplemental Materials Appendix for Module #2; See Symbol Glossary in Supplemental Materials Appendix for all Modules)

6) Challenge: Decode & Encode Atomic Symbols  
Applicable to: Atomic Symbols of all elements  
Possible Activities  
  • Side Note Atomic Symbol Key: In the student notes packets, place a glossary box in the margins that defines the new symbols. For example, the meaning behind the positions of numbers in atomic symbols should be explicitly explained. Alternatively, an entire symbol glossary can be provided. (See Glossary #3 in Supplemental Materials Appendix for Module #2; See Symbol Glossary in Supplemental Materials Appendix for all Modules)  
  • Making Nuclear Symbols just Clear Symbols - Using the symbol glossary as a reference, explicitly demonstrate the metacognitive process to analyze the individual symbols within an atomic (AKA Nuclear) symbol in order to calculate the number of subatomic particles or identify the name of the element. Additionally, equations can be provided, as shown below, either in the form show below or in more user-friendly pictorial formats. Alternatively, reference the following mnemonic device: Remember that the mass number is the superscript by thinking "Super Massive" Remember that the atomic number is the subscript by thinking "Subatomic particle" (See Glossary #3 in Supplemental Materials Appendix for Module #2; See Symbol Glossary in Supplemental Materials Appendix for all Modules)  

| mass number   | 4
| atomic number | 2

Atomic Number = Number of Protons  
Number of Protons → Identify of Element  
Number of Protons = Number of Electrons  
Mass Number - Atomic Number = Number of Neutrons
Instructional Resources and Materials to engage students in learning:

1) Module Specific: See Supplemental Materials Appendix for Module #2 below

Images
- **Image #1**: Atomic Radii for Simplified Periodic Tables
- **Image #2**: Electronegativity Trends for Simplified Periodic Tables
- **Image #3**: Metals, non-metals and metalloids for Simplified Periodic Tables
- **Image #4**: Lewis Dots for Simplified Periodic Tables
- **Image #5**: Trend Comparisons A for Simplified Periodic Tables
- **Image #6**: Trend Comparisons B for Simplified Periodic Tables
- **Image #7**: Families and groups for Simplified Periodic Tables
- **Image #8**: 3D Periodic Table for Emphasized Trend Periodic Tables
- **Image #9**: Circle & Dot Periodic Table for Alternative Depictions of the Periodic Table
- **Image #10**: Circular Periodic Table for Alternative Depictions of the Periodic Table
- **Image #11**: Mayan Periodic Table for Alternative Depictions of the Periodic Table
- **Image #12**: Rainbow Periodic Table for Alternative Depictions of the Periodic Table
- **Image #13**: Spiral Periodic Table A for Alternative Depictions of the Periodic Table
- **Image #14**: Spiral Periodic Table B for Alternative Depictions of the Periodic Table

Worksheets
- **Worksheet #1**: Graphic Organizer for Scalar Depictions of Elements
- **Worksheet #2**: Narrative Support and Example for Turning Lead into Gold Creative Writing
- **Worksheet #3**: Translation Challenge for Alien Periodic Table
- **Worksheet #4**: Graphic Organizer for Atomic History

Module Specific Glossaries
- **Glossary #1**: Etymology of Atomic and Elemental Morphemes
- **Glossary #2**: Vocabulary of Atomic and Elemental Terms
- **Glossary #3**: Symbols of Atomic Models

2) General: See Supplemental Materials Appendix for all Modules

Glossaries
- **Glossary #1a**: Etymology Glossary for Scientific Terminology & Concepts
- **Glossary #2**: Vocabulary Glossary for Scientific Concepts and Terminology
- **Glossary #3**: Symbol Glossary for Mathematic and Chemical Symbols

Regents Reference Tables Supports
- **Regents Reference Table Support #1**: Links for Navigating Regents Reference Tables
- **Regents Reference Table Support #2**: Link to Interactive Online Periodic Table
- **Regents Reference Table Support #3**: Etymological Analysis of Elemental Names
Relevant theories and/or research best practices:

What theories and scholarly sources ground your decisions about the learning tasks?

1) General Theories
   Linguistic Etymology, Specialized Glossaries, Mnemonic Devices, Visual supports, Metacognition, Code-switching & Translation

2) Research Articles
   Etymology
   
   Contradictory Definitions (Colloquial vs Scientific Language)

   Metacognitive and other Linguistic Supports

   Specialized Glossaries

   Code-Switching
Periodic Table Adaptations and Strategies

Appendix of Supplemental Materials for Module Kit #2

Image #1: Atomic Radii for Simplified Periodic Tables

Atomic Radii (periodic table)

Image #2: Electronegativity Trends for Simplified Periodic Tables

Electronegativity

Pauling scale
Image #3: Metals, non-metals and metalloids for Simplified Periodic Tables

![Metals, non-metals and metalloids for Simplified Periodic Tables](image3)

Image #4: Lewis Dots for Simplified Periodic Tables

![Lewis Dots for Simplified Periodic Tables](image4)

Image #5: Combined Comparisons A for Simplified Periodic Tables

![Combined Comparisons A for Simplified Periodic Tables](image5)
**Image #6:** Trend Comparisons B for Simplified Periodic Tables

**Image #7:** Families and groups for Simplified Periodic Tables
Image #8: 3D Periodic Table for Emphasized Trend Periodic Tables

Image #9: Circle & Dot Periodic Table for Alternative Depictions of the Periodic Table
**Image #10:** Circular Periodic Table for Alternative Depictions of the Periodic Table

**Image #11:** Mayan Periodic Table for Alternative Depictions of the Periodic Table

*The Mayan Periodic Chart of the Elements*
Image #12: Rainbow Periodic Table for Alternative Depictions of the Periodic Table

PERIODIC TABLE
EG Marks & JA Marks
1994

Image #13: Spiral Periodic Table A for Alternative Depictions of the Periodic Table
Image #14: Spiral Periodic Table B for Alternative Depictions of the Periodic Table
Worksheet #1: Graphic Organizer for Scalar Depictions of Elements

Scalar Depictions of Elements

Instructions: This graphic organizer is divided into three sections, each with two boxes for two elements of your choice. In Part A, Macroscale, you will name any two elements you want and draw a picture of what you see when you look at those elements with your own eye. In Part B, Submicroscale, you will draw the same two elements, but what you would see only with the support of an electron microscope (atoms within a sample of the element). In Part C, Symbols, you will draw an atomic model of one atom for both elements using whichever historical model you would prefer. Said model should show protons, neutrons and electrons, though they do not necessarily have to show the exact numbers of those subatomic particles.

Part A: Macroscale
Clue: What can you see with just your eyes?

<table>
<thead>
<tr>
<th>Element #1 Name:</th>
<th>Element #2 Name:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part B: Submicroscale
Clue: How far apart do you think atoms are in your element (Is it a solid, liquid or gas?)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part C: Symbolic Scale
Clue: Pick an atomic model. Use the periodic table to count protons, electrons and neutrons.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Profiles from Elementity.com
A Social Networking Site for Unique Chemical Particles

Background: Below are the profiles of our chemistry friend, Lead, as she transitions through radioactive decay and ionization, eventually becoming Gold. Read her changing profiles and her journal entries, and fill in the blanks with the correct number of specified subatomic particles or circle the correct word choice as provided. Definitions are provided below.

Element: The most common atomic form of the specified element; the atomic charge is neutral because the number of protons & electrons are equal (#Protons = Atomic Number). To find the number of neutrons, round the given atomic mass to the closest integer and calculate the number of neutrons. (Atomic Mass→ Round it!→ Most Common Mass # & Mass# − #Protons = #Neutrons)

Isotope: An atom that has a different number of neutrons from the most common form of the element (defined above).

Ion: An atom that has a differing number of electrons to protons, & a nonzero charge. (#Protons + #Electrons = Charge)

I am: Mercury (Hg)
My atomic # is: _80_
Avg. Mass #: _201_ amu
I have: _80_ protons
_121_ neutrons
_80_ electrons

I am: Lead (Pb)
My atomic # is: _82_
Avg. Mass #: _207_ amu
I have: _82_ protons
_125_ neutrons
_82_ electrons

I am: Thallium (Tl)
My atomic # is: _81_
Avg. Mass #: _204_ amu
I have: _81_ protons
_123_ neutrons
_81_ electrons

I am: Gold (Au)
My atomic # is: _79_
Avg. Mass #: _197_ amu
I have: _79_ protons
_118_ neutrons
_79_ electrons

Worksheet #2: Narrative Support and Example for Turning Lead into Gold Creative Writing
**Fill in the Blank Narrative**

**Day 1:** Omg, today was so weird. I don't know why, but I spontaneously lost 2 of my neutrons. I feel so awkward, like I'm not as impressive or important as I was. Now I'm such an __________ (Element, Isotope or Ion). :/ At least I still have #____ neutrons left. And my numbers of protons and electrons are still both #____, which means I am ________ (which element?). Strange...

**Day 2:** Ugh, today did not get any better. I lost 1 electron. My friend, Chlorine asked if I was certain. Yes, I'm totally positive! I know what I lost! >:( I have #____ protons, but only #____ electrons. I feel so imbalanced. But at least I am still ______ (which element?) now. But something is still so out of whack. I think I'm a total ____________ (Element, Isotope, Ion) too....

**Day 3:** Today, I was sick of feeling imbalanced. I was going to take charge, and do what I had to do to feel better. So I kicked out 1 of my protons! Yeah! I feel like I just lost so much drama, and I feel much more stable. I know who I am now. I AM ________ (which element?) and I AM an ______________ (Element, Isotope, Ion)!

**Day 4:** No way! NO way! My stability yesterday was surprisingly short-lived. :( Today, I lost 1 proton AND 1 electron! I only have #____ left of each... Everything is so heavy though. I feel so depressed and sluggish. I have #____ neutrons, which is just weighing me down. Everything is so different! I'm not who I was anymore, now I'm ________ (which element?), but I'm also an _______________ (Element, Isotope or Ion) again. So weird...

**Day 5:** Why does this week just keep getting worse!?! Today, I said goodbye to 2 more neutrons. It's weird, but even though I lost them, I do feel a bit lighter. It's almost like a weight has been lifted off of me. *sigh* Right now, I have #____ protons, #____ electrons, and #____ neutrons. But that's ok. Now I am truly ______ (which element?), a real __________________ (Element, Isotope or Ion). I just hope this is the last of these crazy changes.

**Day 6:** Seriously, did today just happen? It did! I lost 1 more proton. *cries* Everything is weighing me down, and I feel so negative, like this will never get better... My dwindling numbers are now #____ protons, #____ electrons, and #____ neutrons. So awkward. I have become ________ (which element?), but I don't feel like I'm worth anything. Even weirder now is that I am both an _______________ (Element, Isotope or Ion) AND an ________________ (Element, Isotope or Ion). What a crazy head-trip.

**Day 7:** Today, I decided to take control of my own destiny. I have value! How could I not? I am precious __________ (which element)!! Today, I rejected 3 neutrons AND 1 electron. I don't need them. I am fine with my #____ protons, #____ electrons, and #______ neutrons. I am happy with who I am. I am a proud _______________ (Element, Isotope or Ion) and I am going to stay this way!
Answer Key or Narrative Example

**Day 1:** Omg, today was so weird. I don't know why, but I spontaneously lost 2 of my neutrons. I feel so awkward, like I'm not as impressive or important as I was. Now I'm such an __________ (Element, Isotope or Ion). :/ At least I still have #123 neutrons left. And my numbers of protons and electrons are still both #82, which means I am ___ Lead____ (which element?). Strange...

**Day 2:** Ugh, today did not get any better. I lost 1 electron. My friend, Chlorine asked if I was certain. Yes, I'm totally positive! I know what I lost! >:( I have #82 protons, but only #81 electrons. I feel so imbalanced. But at least I am still ___Lead____ (which element?) now. But something is still so out of whack. I think I'm a total ____________ (Element, Isotope, Ion) too....

**Day 3:** Today, I was sick of feeling imbalanced. I was going to take charge, and do what I had to do to feel better. So I kicked out 1 of my protons! Yeah! I feel like I just lost so much drama, and I feel much more stable. I know who I am now. I AM ___Thallium____ (which element?) and I AM an ______________ (Element, Isotope, Ion)!

**Day 4:** No way! NO way! My stability yesterday was surprisingly short-lived. :( Today, I lost 1 proton AND 1 electron! I only have #80 left of each... Everything is so heavy though. I feel so depressed and sluggish. I have #123 neutrons, which is just weighing me down. Everything is so different! I'm not who I was anymore, now I'm ___Mercury____ (which element?), but I'm also an ______________ (Element, Isotope or Ion) again. So weird...

**Day 5:** Why does this week just keep getting worse?!?! Today, I said goodbye to 2 more neutrons. It's weird, but even though I lost them, I do feel a bit lighter. It's almost like a weight has been lifted off of me. *sigh* Right now, I have #80 protons, #80 electrons, and #121 neutrons. But that's ok. Now I am truly ___Mercury____ (which element?), a real _______________ (Element, Isotope or Ion). I just hope this is the last of these crazy changes.

**Day 6:** Seriously, did today just happen? It did! I lost 1 more proton. *cries* Everything is weighing me down, and I feel so negative, like this will never get better... My dwindling numbers are now #79 protons, #80 electrons, and #121 neutrons. So awkward. I have become ___Gold____ (which element?), but I don't feel like I'm worth anything. Even weirder now is that I am both an _______________ (Element, Isotope or Ion) AND an _______________ (Element, Isotope or Ion). What a crazy head-trip.

**Day 7:** Today, I decided to take control of my own destiny. I have value! How could I not? I am precious ___Gold____ (which element)!! Today, I rejected 3 neutrons AND 1 electron. I don't need them. I am fine with my #79 protons, #79 electrons, and #118 neutrons. I am happy with who I am. I am a proud ____________ (Element, Isotope or Ion) and I am going to stay this way!
Worksheet #3: Translation Challenge for Alien Periodic Table

The Alien Periodic Table Activity

Aliens have been discovered. Their language has been partly translated by language experts, however the language experts do not know enough chemistry to correctly translate some of the alien's scientific language. You are a part of a team of four scientists who are competing against other teams of scientists to be the first to translate the names of the alien's elements into English.

Below are descriptions about each alien element that the language experts were able to translate. You and your group of scientists need to uncover which alien elements match which English elements.

------

A note from the language experts: So far, the aliens have only discovered 18 elements, which are prevalent on their planet. Although the names of the elements are different, they must correspond to our elements if our belief of universal elements holds true.

Instructions: Read each clue carefully, and then write both the alien symbol and English symbol for that clue's element in the blank periodic table provided.

________________ - 1. Blorzik (Bz): The aliens say that this element is responsible for simple life forms, such as humans. It has 2 electron energy levels and 4 electrons available for bonding in the outermost energy level.

________________ - 2. Grunklak (Gk): This element is the building block of alien life. It bonds similarly to Blorzik (Bz), but it has more mass. It is why the aliens are silver and why they are able to combine their semiconductor bodies with electronic technology.

________________ - 3. Kryll (Kl): The aliens state that this element is only able to make 1 bond. They also say the element is incredibly unique, because it is the only element with no neutrons.

________________ - 4. Spiklox (Sx): The aliens say that Spiklox is vital to human life. It has slightly more mass than Blorzik, at approximately 16 amu.

________________ - 5. Flakk (Fk): The aliens are very pleased that this element is so abundant on earth as a diatomic gas, because it is the element that they breath. They do note that if humans only breath Flakk, they die. Also, Flakk has 7 neutrons.

________________ - 6. Klurf (Kf): This is the smallest element that does not make any bonds. The aliens say that its behavior is inert.
7. Zaxlig (Zx): The aliens warn that this element is very dangerous to both humans and aliens because it is so very reactive that it will "steal" 1 electron from whatever it touches.

8. Globz (Gz): The aliens warn that this element is so very reactive that it is not found naturally in its pure elemental form on earth or their home planet. They note that humans seem to eat a lot of this element when it is combined with Zirifork.

9. Zirifork (Zk): This element behaves very similarly to Zaxlig, but has more mass. It has 17 protons.

10. Zopigak (Zp): This is the largest element of all the elements that the aliens have discovered. It is inert.

11. Boriplaz (Bp): The aliens warn that this element can create very dangerous fires, that burn with a white flame, and cannot be extinguished with water or human fire extinguishers. It typically forms 2 bonds and has 12 electrons overall.

12. Forlaz (Fz): Both aliens and humans use lots of metallic Forlaz, because it is ductile and a good conductor. The number of electrons in each of its shells are 2, 8 and 3.

13. Goxzor (Gx): This brittle metal is used primarily in the alien and human military. It makes 2 bonds, but has 4 electrons.

14. Xoggle (Xg): The aliens say that this metal is so soft that it can be cut with a knife, but it is dangerously explosive when exposed to the liquid that humans drink. This element has similar reactivity to Globz in that it forms only 1 bond.

15. Bogazirk (Bg): This element is a yellow solid at room temperature. It burns with a blue flame and when melted with heat, it is a red liquid. It has 2 electron energy levels and 6 electrons available for bonding in the outermost energy level.

16. Glyfikor (Gf): The aliens say that this gaseous element refuses to bond and thus does not form any compounds. However, when electricity is run through Glyfikor, it emits bright reddish-orange light.

17. Kilzog (Kz): The most common form of this element has the same number of neutrons as Blorzik, but fewer protons. The second most common form of Kilzog is used in nuclear reactors, because of its ability to absorb neutrons.

18. Flooxig (Fx): When this element is exposed to Spiklox, the aliens note that it glows dimly. It is also interesting that the most common form of Flooxig has 16 neutrons, but not the same number of protons.
**Answer Key**

1. Blorzik (Bz) = Carbon (C)
2. Grunklak (Gk) = Silicon (Si)
3. Kryll (Kl) = Hydrogen (H)
4. Spiklox (Sx) = Oxygen (O)
5. Flakk (Fk) = Nitrogen (N)
6. Klurf (Kf) = Helium (He)
7. Zaxlig (Zx) = Fluorine (F)
8. Globz (Gz) = Sodium (Na)
9. Zirifork (Zk) = Chlorine (Cl)
10. Zopigak (Zp) = Argon (Ar)
11. Boriplaz (Bp) = Magnesium (Mg)
12. Forlaz (Fz) = Aluminum (Al)
13. Goxzor (Gx) = Beryllium (Be)
14. Xoggle (Xg) = Lithium (Li)
15. Bogazirk (Bg) = Sulfur (S)
16. Glyfikor (Gf) = Neon (Ne)
17. Kilzog (Kz) = Boron (B)
18. Flooxig (Fx) = Phosphorus (P)
**Worksheet #4: Graphic Organizer for Atomic History**

**The History of the Atom**

**Directions:** Read the description of the model of the atom that you were given and answer the questions that pertain to that model.

<table>
<thead>
<tr>
<th><strong>Model</strong></th>
<th>Question</th>
<th>Additional Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dalton</td>
<td>What is the structure of the atom according to this model?</td>
<td>Draw a diagram of this model of the atom</td>
</tr>
<tr>
<td>Thomson</td>
<td>How was this model discovered?</td>
<td>Draw a diagram of this model of the atom</td>
</tr>
<tr>
<td></td>
<td>What is the structure of the atom according to this model?</td>
<td></td>
</tr>
<tr>
<td>Rutherford</td>
<td>How was this model discovered?</td>
<td>Draw a diagram of this model of the atom</td>
</tr>
<tr>
<td></td>
<td>What is the structure of the atom according to this model?</td>
<td></td>
</tr>
<tr>
<td>Bohr</td>
<td>How was this model discovered?</td>
<td>Draw a diagram of this model of the atom</td>
</tr>
<tr>
<td></td>
<td>What is the structure of the atom according to this model?</td>
<td></td>
</tr>
<tr>
<td>Model Description</td>
<td>Questions</td>
<td>Additional Task</td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Quantum (wave) mechanical model (a.k.a modern model)</td>
<td>How was this model discovered?</td>
<td>Draw a diagram of this model of the atom</td>
</tr>
<tr>
<td></td>
<td>What is the structure of the atom according to this model?</td>
<td></td>
</tr>
<tr>
<td>Future Atomic Model?!?!?</td>
<td>What would have to be discovered for your atomic model to exist?</td>
<td>Draw a diagram of this model of the atom</td>
</tr>
<tr>
<td>Design your own idea for what the atomic model might look like in the future</td>
<td>What is the structure of the atom according to this model?</td>
<td></td>
</tr>
</tbody>
</table>
Module-specific Glossary #1: Etymology of Atomic and Elemental Morphemes

Etymological Glossary for Module #2

<table>
<thead>
<tr>
<th>Word</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>al</td>
<td>See ial</td>
<td></td>
</tr>
<tr>
<td>an</td>
<td>(Greek) Up</td>
<td>Ex: Anion</td>
</tr>
<tr>
<td>atom</td>
<td>(Greek) Indivisible</td>
<td>Ex: Atomic</td>
</tr>
<tr>
<td>bol</td>
<td>(Greek) Cast (AKA model)</td>
<td>Ex: Symbol</td>
</tr>
<tr>
<td>cat</td>
<td>(Greek) Down</td>
<td>Ex: Cation</td>
</tr>
<tr>
<td>electr</td>
<td>(Old English) Electric</td>
<td>Ex: Electron</td>
</tr>
<tr>
<td>element</td>
<td>(Latin) Basic principle, rule</td>
<td>Ex: Elemental</td>
</tr>
<tr>
<td>ial</td>
<td>(Latin) Related to</td>
<td>Ex: Orbital</td>
</tr>
<tr>
<td>ic</td>
<td>(Latin) Pertaining to</td>
<td>Ex: Symbolic, Ionic</td>
</tr>
<tr>
<td>ion</td>
<td>(Greek) To go</td>
<td>Ex: Ionic</td>
</tr>
<tr>
<td>iso</td>
<td>(Latin) State or action of</td>
<td>Ex: Observation</td>
</tr>
<tr>
<td>macro</td>
<td>(Greek) Long</td>
<td>Ex: Macroscale</td>
</tr>
<tr>
<td>micro</td>
<td>(Greek) Small</td>
<td>Ex: Submicroscale</td>
</tr>
<tr>
<td>neutr</td>
<td>(Old English) Neutral</td>
<td>Ex: Neutron</td>
</tr>
<tr>
<td>nucleus</td>
<td>(Latin) Kernel or inner part</td>
<td>Ex: Nucleus</td>
</tr>
<tr>
<td>orbit</td>
<td>(Latin) Course or track</td>
<td>Ex: Orbital</td>
</tr>
<tr>
<td>particle</td>
<td>(Latin) Little part</td>
<td>Ex: Particle</td>
</tr>
<tr>
<td>prot</td>
<td>(Greek) First or most important</td>
<td>Ex: Proton</td>
</tr>
<tr>
<td>sub</td>
<td>(Latin) Below or under</td>
<td>Ex: Submicroscopic</td>
</tr>
<tr>
<td>sym</td>
<td>(Latin) Same</td>
<td>Ex: Symbol</td>
</tr>
<tr>
<td>tope</td>
<td>(Greek) Place</td>
<td>Ex: Isotope</td>
</tr>
</tbody>
</table>

Examples of Etymological Analysis

- **Anion**: an + ion
  - **CLUE**: Ion with an increased negative charge due to gaining an electron
  - **Ion going up**
- **Atomic**: atom
  - **CLUE**: If you divide an atom, it no longer has the characteristics of the element
  - **Pertaining to being indivisible**
- **Cation**: cat + ion
  - **CLUE**: Ion with an decreased negative charge due to losing an electron
  - **Ion going down**
- **Electron**: electr + (i)on
  - **Electric Ion**
- **Ion**: ion
  - **To go**
- **Isotope**: iso + tope
  - **Same Place**
CLUE! Because Isotopes are all the same element

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron</td>
<td>neutr + (i)on</td>
</tr>
<tr>
<td>Nucleus</td>
<td>nucleus</td>
</tr>
<tr>
<td>Orbital</td>
<td>orbit + al</td>
</tr>
<tr>
<td>Proton</td>
<td>prot + (i)on</td>
</tr>
</tbody>
</table>

CLUE! Because the Nucleus is the inner part of the atom

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submicroscale</td>
<td>sub + micro + scale</td>
</tr>
</tbody>
</table>

Symbol sym + bol   Same model

CLUE! Because symbols are models of (almost the same as) the thing they represent
Module-specific Glossary #2: Vocabulary of Atomic and Elemental Terms

Vocabulary Glossary for Module #2

Anion
A negatively charged ion
(Translation) An atom that has more electrons than protons
Note: Refer to Charge and Ion

Atom
The smallest particle of an element that retains the chemical properties of the element.
(Translation) A basic unit of matter that has a nucleus, made of protons and neutrons, and an electron cloud.
Note: Compare to Element and Subatomic Particles

Atomic Mass
The average mass of an atom of an element, which is the weighted average of the masses of every isotope found in a typical sample of the element.
(Translation) The weighted average of the mass numbers of all naturally occurring isotopes of an atom; given on the periodic table.
Note: Refer to Element and Isotope
Note: Compare to Mass number

Atomic Model
A structural depiction of an atom of an element on the subatomic scale, which often shows the subatomic particles.
Note: Refer to Atom

Atomic Number
The number of protons in the nucleus of an atom, which determines an element's structure, properties and location of the periodic table.
(Translation) The number of protons in an atom that defines the element.
Note: Refer to Protons

Cation
A positively charged ion
(Translation) An atom that has more protons than electrons
Note: Refer to Charge and Ion

Charge
A property of matter that is responsible for electrical phenomenon

Electron
A negatively charged subatomic particle found outside the nucleus of an atom that has a mass of approximately 1/1000 amu
Note: Compare to Proton and Neutron

Electron Cloud
The area outside the nucleus of an atom where electrons reside

Element
A substance that is only composed of the same atoms, all which have the same atomic number.
Note: Compare to Atom
Note: Refer to Atomic number

Ion
An atom or molecule that has acquired a charge by either gaining or losing electrons.

Isotope
An atom of an element that has the same atomic number, but a different mass number.
(Translation) An atom of an element that has the same number of protons, but a different number of neutrons in their nucleus.

**Note:** Compare to *Atom* and *Ion*

<table>
<thead>
<tr>
<th><strong>Mass Number</strong></th>
<th>The total number of protons and neutrons in an atom of an element.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neutron</strong></td>
<td>A subatomic particle with no charge found inside the nucleus of an atom that has a mass of 1 amu</td>
</tr>
<tr>
<td><strong>Nucleus</strong></td>
<td>The dense positively charged mass at the center of the atom, which contains protons and neutrons.</td>
</tr>
<tr>
<td><strong>Proton</strong></td>
<td>A positively charged subatomic particle found inside the nucleus of an atom that has a mass of 1 amu</td>
</tr>
<tr>
<td><strong>Subatomic</strong></td>
<td>A particle that is smaller than an atom, which makes up an atom</td>
</tr>
<tr>
<td><strong>Particle</strong></td>
<td></td>
</tr>
</tbody>
</table>
Module-Specific Glossary #3: Symbols of Atomic Models

Vocabulary Glossary for Module #2

Singular Symbols

e\textsuperscript{−} \hspace{1cm} \text{electron (sometimes shown as e)}
n \hspace{1cm} \text{neutron (sometimes shown as n}\textsuperscript{0})
p \hspace{1cm} \text{proton (sometimes shown as p}^{+})

Models

- Dalton's Atomic model
- Thompson's Atomic Model, also called the Plum Pudding Model
- Rutherford's Atomic model, also called the Nuclear Model
- Bohr's Atomic Model, also called the Planetary Model
- Wave-Mechanical Atomic Model, also called the Modern or Quantum Model

Types of Symbol Notation

Atomic Symbol

The combination of the elemental symbol with the mass number and the atomic number, and sometimes the charge. Also called the nuclear symbol.

\[
\begin{array}{c}
\text{M} \\
\text{A} \\
\text{X}^{+/-}
\end{array}
\]

(Looks like)
Mass Number
The total mass of that atom (protons plus neutrons)
(Example) \[ ^{4}_{2} \text{He} ^{0} \]
(Looks like) \[ M \ X \ +/- \]

Atomic Number
The total number of protons of that atom
(Example) \[ ^{4}_{2} \text{He} ^{0} \]
(Looks like) \[ M \ X \ +/- \]

Elemental Symbol
The alphabetical abbreviation of the name of an element, which can be found on the periodic table.
(Example) \[ ^{4}_{2} \text{He} ^{0} \]
(Looks like) \[ M \ X \ +/- \]

Charge
The electrical charge of the atom, which can be used to infer the number of electrons. Can be positive, negative or neutral.
(Example) \[ ^{4}_{2} \text{He} ^{0} \]
(Looks like) \[ M \ X \ +/- \]
Module Kit #3

College at Brockport, Department of Education & Human Development
Linguistic Strategies for Chemistry - Module #3
Designed by Genevieve Criss

Associated Chemistry Unit:  Unit #3: The Electron
Unit Subject or Content area:  Electron Configurations, Energy Levels, Lewis Dot Structures
Module Title: Pronouncing the Chemical Alphabet Phonetically: Electron Configurations

Module Overview Provide a narrative that explains what language needs this module supports and why it is relevant? The third unit of chemistry focuses on the underlying characteristics that predict chemical behavior: electron configurations. The number of valence electrons in any atom determines how it bonds to other atoms, including number of bonds and even type of bonds. Therefore, the act of determining electron configuration from the identity of the element through the periodic table is parallel to the phonetic alphabet. Just as students sound out letters in the alphabet to figure out how those letters will combine into words, students too can use electron configurations to predict how atoms will react chemically.

The central learning objective here is an extension from the second unit's goal for students to be able to 'read' the periodic table. Here, the students must be able to extract information about electron configurations, which requires decoding the periodic table and then encoding that information into one of four notation types. In later units, students will be able to predict bonding behavior based on these electron configurations.

Second, students must also be able to present electron configurations not only in the multiple notation 'dialects', but also in visual dialect of Lewis Dot Structures or other atomic models. Lewis Dot Structures are a simplified depiction of electron configurations, that are easier for students to use to predict bonding behavior. In fact, while Lewis Structures in this unit are only used to represent atoms and single ions, in later units they will form compounds, the chemical equivalent to words! It is important to note that the ability to draw these representations requires linguistic and heuristic support from the educator to ensure students' mastery of these skills.

This section is features a dangerous pitfall; the topic of energy behavior. Excited states, orbitals and electron spin are concepts that are easily misconstrued linguistically, thus they require support from other strategic areas. A fascinating bonus, however, is that when speaking on the scientists who developed critical theories into energetic electron behavior, built off each other's work despite not always speaking the same common language. Thus, the section does provide the opportunity to demonstrate that chemistry spans across countries and languages across the world by acting as it's own language, a lingua franca.

Module Objective(s): Develop an objective statement that aligns with the language needs and uses observable and measurable goals. The primary goal of this module is to further familiarize students with the Periodic Table and build the skills needed for them to decode and encode information on electron configurations in various formats. Specific objectives are:

- When asked to determine the electron configuration of an element in a specific notation type, students will be able to accurately write the electron configuration with the use of the periodic table and Table S as needed.
- When provided only with an electron configuration, students will be able to determine the elemental identity with the use of the periodic table and Table S as needed.
- When challenged to draw the Lewis Dot Structure or an equivalent quantified atomic model of a novel element, students will be able to correctly depict said symbol or model with the use of the periodic table and Table S as needed.
- When asked about the energy level of a specific orbital (or sub-orbital), students will be able to state
whether that energy level lies above or below another referenced orbital.

- When asked to determine an excited electron configuration of an element in a specific notation type, students will be able to accurately write at least one excited electron configuration with the use of the periodic table and Table S as needed.
- When asked to explain an energetic phenomenon regarding electrons, students will be able to explain that phenomenon in both scientific and colloquial language to demonstrate authentic understanding.
- When asked to define a scientific term or to express a relationship between two terms, students should be able to provide answers in both scientific and colloquial language to demonstrate authentic understanding.

Content Outline

1) Knowledge

- Etymology: Various
- Symbols: Lewis Dot Structures, Major Energy Level Notation (2-8-18-32), Spectroscopic Notation (1s² 2s² 2p⁶ 3s² 3p⁶ 4s² 3d⁶ 5p⁶ 6s² 4d¹⁰ 5p⁶ 6s² 4f¹⁴ 5d¹⁰ 6p⁶ 7s² 5f¹⁴ 6d¹⁰ 7p⁶), Orbital Notation (↑↓/1s ↑↓/2s ↑↓/2pₓ ↑↓/2pᵧ ↑↓/2pₜ), Noble gas ([Rn] 7s² 5f¹⁴ 6d¹⁰ 7p⁶)

2) Skills

- Ability to... Decode, Encode & Translate between Various Electron Configurations
- Ability to... Decode, Encode & Translate between Lewis Dot Structures & Quantified Atomic Models
- Ability to... Distinguish between colloquial & scientific meaning regarding Energy concepts

3) Values

- Demonstrate... Recognition of the Relevance of Chemical Language across the Globe

Activities and Instructional Strategies

1) Challenge: Differentiation of Paired/Related Concepts
Applicable to: Ground State vs Excited State, Notation Types,

Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notation Types</td>
<td>Electron Notation Types Together</td>
<td>Provide students with a blank graphic organizer that is has 4 columns, one for each Notation type. Each row has a specific element, which students need write in each notation type. That way the students can see the equivalent forms of notations. (See Worksheet #1 in Supplemental Materials Appendix for Module #3)</td>
</tr>
<tr>
<td>Ground State vs Excited</td>
<td>Electron Orbital</td>
<td>Ask for a student volunteer to help present the analogy of excited electron states with a basketball free throw. Explain</td>
</tr>
</tbody>
</table>
State | Basketball | that the student represents an atom, that the ball represents the electron and cheering represents Energy. When the student is waiting (on the ground) to throw the ball for a free throw, the student (aka atom) is in the ground state. When the crowd cheers, that excitement (aka Energy) is absorbed by the atom, who then jumps up and throws the electron (into the excited state)! However, a high energy state such as the excited state is difficult to maintain so the student and the ball fall back down to the ground (Ground state). When they hit the ground, the energy is released back into the crowd who cheers again!

2) Challenge: Differentiation of Scientific & Colloquial Meanings
Applicable to: Energy, Quantum, Orbital, Spin
Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum, Energy, Excited</td>
<td>Conversations on Colloquial Misuses</td>
<td>Provide students with a scientific definition and examples of colloquial misuse. Ask the student to compare the two and to critically assess the misunderstanding and miscommunication that could have resulted from such use. (See Image #1 from link: <a href="http://www.smbc-comics.com/?id=2628">http://www.smbc-comics.com/?id=2628</a> in the Supplemental Materials Appendix for Module #3)</td>
</tr>
<tr>
<td>Orbital</td>
<td>Electron Orbital Visualization</td>
<td>Provide students with a visual depiction of an electron orbital, such as a PhET simulation or Sprech &amp; Raley's Carbon Paper &amp; Marble activity. Compare and contrast to a visual depiction of a typical planetary orbit.</td>
</tr>
<tr>
<td>Spin</td>
<td>Magnets! How do they work?</td>
<td>Present the students with a video or live demonstration of the behavior of a spinning magnet. Explain to them how electron spin exhibits some of the same behaviors as a spinning magnet, but does not necessarily exhibit the same physical behavior of spinning. Hence, why the term electron spin is used. It is particularly important here to explicitly explain that analogies are limited in their ability to explain scientific phenomena and that the misunderstandings of electron spin result from not recognizing where the analogy 'ends'!</td>
</tr>
</tbody>
</table>

3) Challenge: Decoding, Encoding & Translating between Quantified Atomic Models
Applicable to: Lewis Dot Structures, Bohr Models
Possible Activities
- How "Bohr"ing are Lewis Dot Structures?: Atomic models represent specific elements. In fact, lewis dot structures and bohr models can represent the same element just using different dialects of chemical language, by depicting all electrons or valence electrons only. Therefore to demonstrate their connection, a periodic table can be presented with atomic models of each element instead of traditional symbols. Students can also be encouraged to draw their own atomic models into a blank periodic table. Alternatively, students could be given a simplified periodic
table or other graphic organizer, within which to draw equivalent Lewis & Bohr models (See Image #2 & #3 in Supplemental Materials for Module #3).

- Extrapolation/Continuation from "Side Notes Atomic Models Key" in Module #2: "Side Notes Atomic Models Key" covered decoding and encoding non-quantified atomic models. Strategies used there can be reviewed and then expanded upon to demonstrate how to adjust non-quantified atomic models to quantified atomic models. Specifically, each subatomic particle should be labeled, and if possible step-wise instructions that explain how it was drawn from information from the periodic table. (See Glossary #3 in Supplemental Materials Appendix for Module #2 and Module #3; See Symbol Glossary in Supplemental Materials Appendix for all Modules)

4) Challenge: Decoding, Encoding & Translating between Various Electron Configurations
   Applicable to: Major Energy Level, Spectroscopic, Orbital & Noble Gas Configurations
   Possible Activities

- Electron Notation Types Together: See Challenge #1 above
- The Electron Apartments at Energy Villa: In this activity, students are given a packet with the electron energy levels laid out like an apartment building. They play the landlord and need to fill the apartments according to certain rules. Each rule corresponds to the Aufbau, Hund or Pauli Exclusion principle. Students should fill out the energy level apartments following the rules, and later explain how this corresponds to the scientific concepts (translating between colloquial and scientific language) as an analogy. (See Worksheet #2 in Supplemental Materials Appendix for Module #3; adapted from http://www.umanitoba.ca/outreach/crystal/resources%20for%20teachers/ Electron%20Configuration%20Activity%20C12-2-5%20&%2006.doc.)
- Endless Analogies: Students may be presented with other analogies for the compilation of electron configurations, such as Liguori's chocolate shop model or they may be encouraged to develop their own.
- "Electron"-ic Battleship: Provide students with laminated copies of the periodic table and dry-erase markers. In order for a student to attack the other student, student a picks an element, student b asks for one of the electron configuration types of that element, and student a answers. If student a correctly stated the electron configuration their attack lands. This activity is a solid way to reinforce learning of electron configurations with translation practice across configuration types. (See Worksheet #3 in Supplemental Materials Appendix for Module #3; For Game mat, print copy of the periodic table; See Regents Reference Table Supports #1 in Supplemental Materials Appendix for All Modules)
- Color-coding the Periodic Table for Electron Configurations - On the students Regents Reference packet show students how to mark or highlight the periodic Table in ways that support their use of the table in the compilation of electron configurations. For example, have the students color the areas within the periodic table for each orbital and energy level. Students are encouraged to develop their own preferred marking systems, which should support student navigation and application of the Periodic Table or Table S. As needed, provide the students with extra support such as the student tips for Regents References packet. (See Regents Reference Table Supports #1 in Supplemental Materials Appendix for All Modules)
- Side Note Electron Configuration Key: In the student notes packets, place a glossary box in the margins that defines the new symbols. For example, the meaning behind the positions of numbers in electron configurations should be explicitly explained via metacognitive modeling. Specifically, each sublevel and orbital symbol should be labeled, and if possible step-wise instructions that explain how it was compiled from information from the periodic table. Further,
comparisons of different electron configurations with labeled symbols can be provided. Alternatively, an entire symbol glossary can be provided. (See Glossary #3 in Supplemental Materials Appendix for Module #3; See Symbol Glossary in Supplemental Materials Appendix for all Modules)

**Instructional Resources and Materials to engage students in learning:**

1) Module Specific: See Supplemental Materials Appendix for Module #3 Below

Images
- **Image #1:** Cartoon for Conversations on Colloquial Misuses
- **Image #2:** Lewis Dot Periodic Table for How "Bohr"ing are Lewis Dot Diagrams?
- **Image #3:** Blank Periodic Table for How "Bohr"ing are Lewis Dot Diagrams?

Worksheets
- **Worksheet #1:** Graphic Organizer for Electron Notation Translation
- **Worksheet #2:** Activity for The Electron Apartments at Energy Villa
- **Worksheet #3:** Instructions for "Electron"ic Battleship

Module Specific Glossaries
- **Glossary #1:** Etymology of Electron Configuration Terms
- **Glossary #2:** Vocabulary of Electron Configurations
- **Glossary #3:** Symbols of Electron Configurations

2) General: See Supplemental Materials Appendix for all Modules

Glossaries
- **Glossary #1a:** Etymology Glossary for Scientific Terminology & Concepts
- **Glossary #1b:** Etymological Glossary for IUPAC Nomenclature terminology
- **Glossary #2:** Vocabulary Glossary for Scientific Concepts and Terminology
- **Glossary #3:** Symbol Glossary for Mathematic and Chemical Symbols

Regents Reference Tables Supports
- **Regents Reference Table Support #1:** Links for Navigating Regents Reference Tables
- **Regents Reference Table Support #2:** Link to Interactive Online Periodic Table
- **Regents Reference Table Support #3:** Etymological Analysis of Elemental Names
Relevant theories and/or research best practices:

What theories and scholarly sources ground your decisions about the learning tasks?

1) General Theories
   - Linguistic Etymology, Specialized Glossaries, Mnemonic Devices, Visual supports, Metacognition, Code-switching & Translation

2) Research Articles

Etymology

Contradictory Definitions (Colloquial vs Scientific Language)

Metacognitive and other Linguistic Supports

Specialized Glossaries

Code-Switching
Electron Representation Adaptations and Strategies


Appendix of Supplemental Materials for Module Kit #3

**Image #1:** Cartoon for Conversations on Colloquial Misuses

**Image #2:** Lewis Dot Periodic Table for How "Bohr"ing are Lewis Dot Diagrams?
Image #3: Blank Periodic Table for How "Bohr"ing are Lewis Dot Diagrams?

<table>
<thead>
<tr>
<th>BLANK PERIODIC TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
**Worksheet #1: Graphic Organizer for Electron Notation Translation**

**Electron Notation Translation**

**Directions:** Write the electron notation for each given element in each of the four notation types (Major energy, spectroscopic, noble gas and orbital notation).

<table>
<thead>
<tr>
<th></th>
<th>Major Energy Level Notation</th>
<th>Spectroscopic Notation</th>
<th>Noble Gas Notation</th>
<th>Orbital Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex: C</td>
<td>2- 4</td>
<td>1s² 2s² 2p²</td>
<td>[He] 2s² 2p²</td>
<td>1s ↑↓ 2s ↑↓ 2p ↑↑</td>
</tr>
<tr>
<td>Na</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ar</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Worksheet #2: Activity for The Electron Apartments at Energy Villa

The Electron Apartments at Energy Villa

Background: Imagine you are the landlord of a very strange apartment building. Your job is to fill the apartments in the building in the most efficient way possible. You are required by the owner of the building to fill the rooms in a certain way. The rules you have to follow are as strange as the building because quantum mechanics is not like anything you might have expected. The rules are summarized in the table below.

In the building the different floors are like the different energy levels (or shells) in an atom. The energy levels are numbered starting from one, just like the floors in an apartment. Each room corresponds to one orbital. The rooms have a capacity of two electrons (two people) each. In each room only a man and a woman may be paired together. In the strange world of quantum mechanics there are no same-gender room mates.

<table>
<thead>
<tr>
<th>Apartment Rules</th>
<th>Electron Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>From the Bottom Up:</strong> Rooms must be filled from the ground floor up. Fill the</td>
<td><strong>Aufbau Principle:</strong> the electrons fill the available orbitals</td>
</tr>
<tr>
<td>one room on the first floor before starting to put new tenants on the second</td>
<td>from lowest energy to highest energy. In the ground state all</td>
</tr>
<tr>
<td>floor. Then fill the s room before the p rooms. At higher floors the order might</td>
<td>the electrons are in the lowest possible energy level.</td>
</tr>
<tr>
<td>change a bit.</td>
<td></td>
</tr>
<tr>
<td><strong>Singles First:</strong> the owner of the building wants to have the tenants spread</td>
<td><strong>Hund’s Rule:</strong> The electrons must be placed into the orbitals</td>
</tr>
<tr>
<td>out as much as possible. For that reason singles are placed in rooms before</td>
<td>in such a way that no pairs are put together unless absolutely</td>
</tr>
<tr>
<td>couples. If couples must be placed into a room then all of the other rooms on</td>
<td>necessary. That is, single electrons must be placed into boxes</td>
</tr>
<tr>
<td>that floor must already have a single in them.</td>
<td>first and then paired up if necessary.</td>
</tr>
<tr>
<td><strong>Opposite Gender Only:</strong> When two people are placed in a room they must be of</td>
<td><strong>Pauli Exclusion Principle:</strong> Electrons come in two varieties</td>
</tr>
<tr>
<td>opposite genders. No men may room together and no women may room together.</td>
<td>based on the direction they are ‘spinning’. There is an Up spin</td>
</tr>
<tr>
<td>This is an arbitrary rule on the part of the owners: in a just world we</td>
<td>and a Down spin. Up and Down spins are always paired together</td>
</tr>
<tr>
<td>wouldn’t have to follow it. But quantum mechanics has nothing to do with justice.</td>
<td>and Up-Up or Down-Down combinations are not allowed. No two</td>
</tr>
<tr>
<td></td>
<td>electrons can ever be in the same place at the same time.</td>
</tr>
</tbody>
</table>

Directions: As the landlord of the Apartments at Energy villa, you need to track down some of your electronic tenants, who are late on their rent. On the next page you are given some information about the electronic tenants, which you can use with the provided energy diagram to determine their apartment number. Consult the given analogy summary as needed.
Example:
The outermost electron of the apartment building, Neon, resides in which apartment and room number? \( 2p^2 \)

1) The two innermost electrons of the apartment building, Oxygen, reside in which apartment number? ____________

2) The two outermost electrons of the apartment building, Silicon, reside in which apartment numbers? ___________ and ____________

3) The outermost electron of the apartment building, Magnesium, resides in apartment number and room number? ____________

4) The last electron on the last completely filled floor of the apartment building, Bromine, resides in which apartment? ____________

5) The two outermost electrons of the apartment building, Sodium, reside in which apartment and room numbers? ___________ and ____________

6) The outermost two electrons of the apartment building, Phosphorus, resides in which apartment and room numbers? ____________ and ____________

7) The two outermost electrons of the apartment building, Beryllium, reside in which apartment and room numbers? ___________ and ____________

<table>
<thead>
<tr>
<th>Chemical Concept</th>
<th>Apartment Analogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atom</td>
<td>Apartment Building</td>
</tr>
<tr>
<td>Nucleus</td>
<td>Basement</td>
</tr>
<tr>
<td>Energy Levels</td>
<td>Floors (staring from first floor and up)</td>
</tr>
<tr>
<td>Sublevels</td>
<td>Apartments</td>
</tr>
<tr>
<td>Orbitals</td>
<td>Rooms</td>
</tr>
<tr>
<td>Electrons</td>
<td>Tenants</td>
</tr>
</tbody>
</table>
Worksheet #3: Instructions for "Electron"ic Battleship

Electron Configuration Activity: You Sunk my Electron Battleship!

Materials: 1 Manila folder per student, 2 Laminated Periodic Tables per Manila Folder, 1 Dry Erase Marker per student

1) Assign the students into pairs. Distribute the folders and markers. Ask students to rearrange their desks so that each partner sits face to face.

2) Explain the typical battleship rules. You may not look at your opponent's periodic tables. On the lower periodic table, each student should circle the areas that represent an aircraft carrier (5 elements), a battleship (4 elements), a submarine (3 elements), a destroyer (3 elements) and a PT boat (2 elements). Each ship may NOT overlap, but they may touch.

3) To launch an attack, the first player calls out the electron configuration of the element that they want to attack (Ex: for Carbon 1s2 2s2 2p2). The other player states the name of the element to verify the correct spot, and then says "hit" or "miss." Both players should mark their boards according to the attack placements. Play until all ships of one opponent is sunk.

4) If desired, teacher can declare at timed intervals, which method of stating configurations should be used to increase difficulty. (Ex: Carbon can be 1s2 2s2 2p2... OR... [He] 2s2 2p2... OR... 2 - 4)
Module-specific Glossary #1: Etymology of Electron Configuration Terms

Etymological Glossary for Module #3

at
ate (Latin) To act by [verb] or to be like [adjective]    Ex: **Configuration**
auf (German) Up    Ex: **Aufbau Theory**
bau (German) Build    Ex: **Aufbau** Theory
con (Latin) Together Ex: **Continuous, Configuration**
ence (Latin) Having the quality or action of    Ex: **Valence**
figur (Latin) Shape    Ex: **Configuration**
ion (Latin) State or action of    Ex: **Configuration**
ous (Old English) Having the nature of    Ex: **Continuous**
scope (Greek) To view or aim    Ex: **Spectroscope**
spectr (Latin) Image    Ex: **Spectrum, Spectroscope**
ten (Latin) To hold Ex: **Continuous**
tin See ten
valen (Latin) Power Ex: **Valence**

Examples of Etymological Analysis

**Aufbau Theory**    auf + bau + theory    The theory of **building up** (electrons)
Electron Configuration con + figur + ate + ion    The action of **shaping** electrons **together**
**Continuous** con + tin + ous    **Having the nature of** holding **together**
**Spectroscope** spectr + scope    (Tool) to view **an image**
**Spectrum** spectr    **Image**
**Valence Electrons** valen + (en)ce    Electrons that **have a powerful quality**

CLUE! Think optical images

CLUE! Valence electrons are the most powerful, because they do all the work (in bonds)!
Module-specific Glossary #2: Vocabulary of Electron Configurations

Vocabulary Glossary for Module #3

Aufbau Principle
A rule for writing ground state electron configurations, in which electrons are filled from lowest Energy levels to highest.
(Translation) Literally, the electron "build-up" rule.
**Note:** Refer to *Electron configurations, Ground state* and *Energy Level*
**Note:** Compare to *Hund's Rule*

Bonding
The attraction between atoms that holds molecules together, which results from electron interactions, such as sharing or transferring.
(Translation) When two atoms share or trade electrons, which causes the atoms to stick together

Electron Configuration
A notation system that describes how many electrons are in each orbital for a specific atom.
**Note:** Refer to *Electron orbital*

Electron Orbital
A division of an energy level that contains two electrons with paired spins and is associated with a specific region of the electron cloud
**Note:** Compare to *Energy level*

Energy Level
The possible locations in the electron cloud, where electrons that have a specific energy value, can be found.
**Note:** Compare to *Electron Orbital*

Excited State
A state in which an atom has temporarily absorbed excess energy, which can result in an electron jumping up to a higher energy orbital or level.
(Translation) A state with higher energy than the ground state of an atom, which can be shown with electron configurations that break Hund's rule.
**Note:** Refer to *Energy Level, Electron Orbital*, and *Hund's Rule*
**Note:** Compare to *Ground State*

Ground State
The lowest energy and thus the most stable state for an atom or molecule, in which electrons reside in the lowest energy levels possible.
(Translation) A state with the lowest energy of an atom, which can be shown with electron configurations that follow Hund's rule.
**Note:** Compare to *Excited State*
**Note:** Refer to *Energy Level, Electron Configuration*, and *Hund's Rule*

Hund's Rule
A rule for writing ground state electron configurations, in which electrons are placed within the orbitals of an energy sublevel, so that the number of unpaired spins is maximized. In other words, electrons should only be paired with another electron within an orbital, after every other orbital within that energy sublevel has one electron occupant.
**Note:** Refer to *Electron configurations, Orbital* and *Energy Sublevel*
**Note:** Compare to *Aufbau Principle*
Quantum  A discrete packet of energy.

Spectroscopy  The analysis of the interaction between electromagnetic radiation, such as light, and matter typically for the purpose of substance identification. (Translation) The study of matter interacting with light

Spectrum  A range of wavelengths of electromagnetic radiation, often visible as colors, that can be used to identify a substance.

Note: Refer to Wavelength

Spin  An intrinsic property of electrons that can be characterized as spin-up or spin-down, which causes magnetic phenomena similar to that of a spinning magnet.

Valence Electron  An electron that resides in the highest energy level of the atom, which can be actively involved in bonding

Note: Refer to Bonding and Energy Level

Wavelengths  The distance, usually in nanometers, between adjacent peaks on a wave, which determines the color of light.
Module-specific Glossary #3: Symbols of Electron Configurations

Symbol Glossary for Module #3

Singular Symbols

\( \uparrow \text{ or } \downarrow \) Indicates directional spin of the electron, used in orbital notation

\([X]\) Indicates the electron configuration of a noble gas, in which \(X\) is

the elemental symbol of the noble gas

d d orbital

f f orbital

p p orbital

p_x p sub-orbital

p_y p sub-orbital

p_z p sub-orbital

s s orbital

Models

Bright Line The spectrum of an incandescent substance that appears as a series of

Spectrum bright lines

Continuous The spectrum of emissions from a substance across a continuous series of

Spectrum wavelengths. Sometimes depicted similarly to the bright line spectrum.

Types of Symbol Notation

Lewis Dot Structure A diagram that depicts the valence electrons shown as dots around

(Looks like) Na

Major Energy Level Notation The simplest notation type for electron configurations, in which

(Looks like) 2 - 8 - 8

Noble Gas Notation A simplified version of the spectroscopic notation type, in which

all filled energy levels can be replaced by an abbreviation of the
electron configuration for the associated noble gas
Orbital Notation
A more complex version of the spectroscopic notation type, in which electrons are represented with arrows to indicate their spin and suborbital location, instead of numerical values.

(See diagram: ↑↓ 1s ↑↓ 2s ↑↓ 2p↑ ↑↓ 2p↓)

Spectroscopic Notation
The most often used notation type for electron configurations, in which energy level, orbital and number of electrons within the orbital are indicated.

(See diagram: 1s^2 2s^2 2p^6)

where the ______ is the...

Numerical Scripts
The energy levels

(Look like: 1s^2 2s^2 2p^6)

Letters (s, p, d or f)
The filled orbitals

(Look like: 1s^2 2s^2 2p^6)

Superscripts
The number of electrons within an energy level and orbital

(Look like: 1s^2 2s^2 2p^6)
Module Overview

The fourth unit of chemistry focuses on the first building block necessary to mentally create molecules: understanding of how atoms bond. Using knowledge from Units #2 & #3, bond type and number can be determined from the number of valence electrons and the placement within the periodic table (which indicates electronegativity trends). Therefore, the act of mentally forming a bond between two atoms is analogous to the combination of letters into syllables. The distinction could even be made that perhaps covalent bonds would represent diphthongs, whereas ionic bonds represent digraphs. This syllable creation step is the precursor combining atoms into molecules, which is practiced in this unit with Lewis Dot structures. In the next unit, students will further combine more atoms into molecules to determine molecular formulas, which is parallel to combining syllables into words.

The central learning objective here is for students to understand and communicate the electron behavior that occurs for each bond type. To accomplish this, students must be able to extract information about electronegativity and valence electrons from the periodic table in order to identify the bond type.

With bond types mastered, students can then encode that bonding information into a polyatomic model, such as a Lewis Dot diagram or other structural depiction, which can indicate molecular geometry and therefore molecular polarity. It is important to note that some polyatomic models will represent incomplete portions of molecules, analogous to chemical syllables, whereas others may depict very simple molecules, analogous to chemical words. Depending on the rate of learning and student comfort, instruction can focus more on whole molecules or incomplete polyatomic models.

Lastly, students will be able to explain the chemical properties that result from the different bonding types as well as intermolecular forces. This requires the students to be able to not only identify the bond type, but also identify molecular polarity as indicated by molecular geometry apparent in the structural depiction.

Overall, this unit expands upon the chemical linguistics and skills of preceeding units, which allows for reinforcement of previous learning via review. Mastery of the above objectives will prepare students in the next unit to progress from encoding incomplete polyatomic combinations to whole molecules. In other words, student will be able to expand from chemical syllables to creating chemical words.

Module Objective(s): Develop an objective statement that aligns with the language needs and uses observable and measurable goals.

The primary goal of this module is promote student ability to identify, depict and explain the electron behavior in bonding, which demonstrates mastery of vocabulary concepts and encoding polyatomic models. This skills reinforce student use of and familiarity with the Periodic table, specifically in regards to electronegativity trends and valence electrons. Specific objectives are:

- When asked to identify the type of bond and/or number of bonds that would result between two atoms, students will be able to accurately name the bond type with the use of the periodic table and Table S as needed.
- When provided with a polyatomic model or equivalent depiction, students will be able to calculate the electronegativity difference between the two atoms with the use of the periodic table and Table S as
needed.
- When asked to explain electron behavior during bonding including resulting energy transfer, students will be able to explain that behavior in both scientific and colloquial language to demonstrate authentic understanding.
- When challenged to draw the Lewis Dot Structure or equivalent polyatomic model, students will be able to correctly depict said combined atoms in regards to both bonds and molecular geometry with the use of the periodic table and Table S as needed.
- When provided with a polyatomic model or other depiction, students will be able to identify which intermolecular forces would exist in that model due to molecular polarity.
- When asked to explain what chemical properties are expressed by a certain bond or molecule, students will be able accurately state the property types and explain how intermolecular forces and/or bond types cause those properties in both scientific and colloquial language to demonstrate authentic understanding.

### Content Outline

1) Knowledge
   - Etymology  Bonding Morphemes
   - Symbols  Review of Lewis Dot Structures, Molecular Geometry Depictions
   - Vocabulary  Bond, Molecule, Covalent, Ionic, Metallic, Polar vs Non-polar, Electronegativity vs Electropositivity, Conductivity, Solid, Liquid, Aqueous, Coordinate Covalent Bonding, Bond Strength, Hardness, Melting Point, Solubility, Intermolecular vs Intramolecular Forces, Phase Change, Van Der Waals Forces, Dispersion Forces, Hydrogen Bonding, Network Covalent Bonding, Molecular Geometry, Linear, Bent, Trigonal Pyramidal, Tetrahedral, Molecular Symmetry, Single, Double & Triple Bonds, Resonance, Polyatomic Ions

2) Skills
   - Ability to...  Recognize the difference in electron behavior for each of the bond types and be able to explain that behavior in both scientific and colloquial language
   - Ability to...  Determine the type of bond (including polarity and number) that occurs between various atomic combinations based on electronegativity differences read from the periodic table
   - Ability to...  Draw Structural Depictions (such as Lewis dot diagrams) of bonds between atoms that indicate the type and number of bonds that occur between various atomic combinations

3) Values
   - Demonstrate...  Recognition of the Systematic Nature of Chemical Language and the Predictive Power that arises from recognizing Linguistic Patterns

### Activities and Instructional Strategies

1) Challenge:  Differentiation of Paired/Related Concepts
   Applicable to:  Electronegative vs Electropositive, Polar Bond vs Polar Molecule, Polar vs Nonpolar, Intermolecular vs Intramolecular, Covalent vs Ionic vs Metallic, Liquid vs Aqueous, Covalent vs Coordinate Covalent, Van Der Waals vs Dispersion Forces

Possible Activities
<table>
<thead>
<tr>
<th><strong>Vocabulary</strong></th>
<th><strong>Support Type</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronegative vs Electropositive, Covalent vs Ionic vs Metallic, Polar vs Non-polar</td>
<td>Elemental Personalities and Behaviors</td>
<td>To foster an intuitive understanding of electronegativity and bonding behavior, chemicals can be described as having &quot;personality traits&quot; such as electron greed or protectiveness. Atoms can be depicted as having a big, medium or little to no sweet-tooth, with electrons represented as candy that is being traded around. Or atoms can be described as either overly-relaxed or overprotective parents, with the electrons as their children. Students can be assigned an element and challenged to write a narrative describing that element's personality &amp; why it works in relation to its atomic characteristics. Additionally, excellent cartoons exist regarding bonding behavior such as polar bonds being depicted as an unevenly matched game of tug of war, metallic bonding depicted as a game of baseball, ionic bonding being depicted as a marriage proposal and many more. (See Images #1 through #6 in Supplemental Materials Appendix for Module #4)</td>
</tr>
<tr>
<td>Polar Bond vs Polar Molecule, Coordinate vs Covalent</td>
<td>Using Molecular Model to Highlight Bonding</td>
<td>Explain or discuss the differences in the vocabulary terms using molecular models as visual support. Depictions will suffice, but physical models are preferred. Color coding to highlight the specific trend or information is suggested (Example: One polar bond within a non-polar molecule highlighted).</td>
</tr>
<tr>
<td>Intermolecular vs Intramolecular, Polar vs Non-polar, Covalent vs Ionic vs Metallic</td>
<td>Analysis of Bonding Morphemes</td>
<td>Using the etymological glossary as a reference, explicitly demonstrate the metacognitive process to analyze the morphemes within foreign words to ascertain their meaning. This process is also known as decoding. (See Glossary #1 in Supplemental Materials Appendix for Module #4; See Symbol Glossary in Supplemental Materials Appendix for all Modules)</td>
</tr>
<tr>
<td>Liquid vs Aqueous</td>
<td>Appearances can be Deceiving!</td>
<td>Either physically demonstrate or play a video that depicts a difference between the liquid and aqueous form of a specific chemical. Giving a clearly differentiated visual (ex: molten salt vs salt water) can reinforce the differentiated definition.</td>
</tr>
<tr>
<td>Van Der Waals vs Dispersion Forces</td>
<td>Intermolecular Forces Hierarchy</td>
<td>Provide students with a blank graphic organizer that is depicts a heirarchal format for students to fill in with the types of forces and their definitions in order to demonstrate relationships and key differences. This graphic organizer can also be expanded to cover other Intermolecular forces (such as dipoles) as well if divided into forces observed in Non-polar molecules, Polar molecules or both.</td>
</tr>
</tbody>
</table>
2) **Challenge:** Differentiation of Scientific & Colloquial Meanings  
**Applicable to:** Bond Strength, Resonance  
**Possible Activities**

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Strength</td>
<td>Bond Strength versus Bond Energy</td>
<td>Bond Strength itself is not terribly different in concept from colloquial use. However, issues arise when relating bond strength to energy, and in future units, strong acids &amp; bases. Many students associate a strong bond as one that is incredibly difficult to break, which is fine. The issue arises when students assume that breaking a bond releases Energy, because they mistakenly believe that a strong bond &quot;stores&quot; that energy. Analogies can be used to explain the direction of energy exchange by drawing a parallel to stable relationships and unstable breakups. Alternatively, an experiment or demonstration can be presented in which water is shown being broken down into it's basic elements with electrolysis, and then explosively reforming into water. (See Worksheet #1 in Supplemental Materials Appendix for Module #4)</td>
</tr>
<tr>
<td>Resonance</td>
<td>Resonance Visualized</td>
<td>Provide students with a visual depiction of a molecule that expresses resonance, such as a PhEt simulation or a physical molecular model with an electron on a rubber band. Compare and contrast to a visual depiction of a sound waves echoing.</td>
</tr>
</tbody>
</table>

3) **Review** **Challenge:** Decoding & Encoding Electronegativity Trends and Valence Electrons from the Periodic Table to Predict Bonding  
**Applicable to:** Determining Bond Type & Number, Electronegativity Difference Calculation  
**Possible Activities**

4) **Challenge:**  
- Extrapolation/Continuation from Challenge #3 in Module #2: "Decoding (Unpacking) the Periodic Table" in Module #2 covered decoding and encoding information from the periodic table. The strategies used there can be reviewed and specified to demonstrate how to determine Electronegativity Trends of the elements.  
- Extrapolation/Continuation from Challenge #4 in Module #3: " Decoding, Encoding & Translating between Various Electron Configurations " in Module #3 covered decoding and encoding electron configurations of elements from the periodic table. The multiple strategies used there can be reviewed and then expanded upon to demonstrate how to predict bonding behavior from the electron configurations of two elements.  
- Octet Rule-Breakers!: Provide students with the a worksheet with 10 electron configurations. Students should determine each element from its electron configuration and draw the associated Lewis Dot diagram of that element. Student will fill out the rest of the worksheet, which challenges them to determine how many and which type of bonds each element is most likely to make. After students initially complete the sheet, ask them to hypothesize and debate amongst themselves which elements might be rule breakers. Eventually inform them which elements in their worksheet do not follow the octet rule. Students should then discuss with a partner what
other ways the octet rule-breaker elements could bond and hypothesize why they are able to do so. Alternatively or additionally, students could be asked to write their own narrative describing the "personality" and "behavior" of one octet rule-breaker element. (See Worksheet #2 in Supplemental Materials Appendix for Module #4)

4) Challenge: Decoding & Encoding More Complicated Structural Depictions
Applicable to: Lewis Dot Diagrams, Ball & Stick Models, Skeletal (or Line-Angle) Structure Possible Activities
- Extrapolation/Continuation from "Side Notes Atomic Models Key" in Module #2 and #3: "Side Notes Atomic Models Key" covered decoding and encoding atomic models, including simple Lewis Dot Diagrams. Strategies used there can be reviewed and then expanded upon to demonstrate how to adjust simple Lewis Dot diagrams to demonstrate bonding via electron sharing or how to draw more complicated Lewis Dot Diagrams.
- Determining Bond Type with Multiple Models: Polyatomic models or simple compounds demonstrate different bond types between specific elements and can be depicted via Lewis Dot Diagrams, Physical Ball & Stick Models or Skeletal Structural Depictions. Therefore to demonstrate their equivalency, students could be given a graphic organizer, within which to draw equivalent Lewis Dot, Skeletal and ball & stick models. This activity can be given as just a graphic organizer for notes, or an inquiry based laboratory activity. (See Worksheet #3 in Supplemental Materials Appendix for Module #4)

**Instructional Resources and Materials to engage students in learning:**

1) Module Specific: See Supplemental Materials Appendix for Module #4 Below
Images
- **Image #1**: Relationships and Breakups Cartoon for Elemental Personalities and Behavior
- **Image #2**: Covalent versus Ionic Bonds Cartoon for Elemental Personalities and Behavior
- **Image #3**: Polar versus Non-polar Bonds Cartoon for Elemental Personalities and Behavior
- **Image #4**: Forming a Bond Cartoon for Elemental Personalities and Behavior
- **Image #5**: Multiple Bonds Cartoon for Elemental Personalities and Behavior
- **Image #6**: Multiple Bonds Cartoon for Elemental Personalities and Behavior
Worksheets
- **Worksheet #1**: Bond Energy Inquiry for Bond Strength Versus Bond Energy
- **Worksheet #2**: Graphic Organizer for Octet Rule Breakers
- **Worksheet #3**: Graphic Organizer for Determining Bond Type with Multiple Models
Module Specific Glossaries
- **Glossary #1**: Etymology of Bonding Terms
- **Glossary #2**: Vocabulary of Bonding Types
- **Glossary #3**: Symbols of Bonding Models

2) General: See Supplemental Materials Appendix for all Modules
Glossaries
- **Glossary #1a**: Etymology Glossary for Scientific Terminology & Concepts
- **Glossary #1b**: Etymological Glossary for IUPAC Nomenclature terminology
- **Glossary #2**: Vocabulary Glossary for Scientific Concepts and Terminology
- **Glossary #3**: Symbol Glossary for Mathematic and Chemical Symbols
Regents Reference Tables Supports
- **Regents Reference Table Support #1**: Links for Navigating Regents Reference Tables
- **Regents Reference Table Support #2**: Link to Interactive Online Periodic Table
- **Regents Reference Table Support #3**: Etymological Analysis of Elemental Names
Relevant theories and/or research best practices:

What theories and scholarly sources ground your decisions about the learning tasks?

1) General Theories
   Linguistic Etymology, Specialized Glossaries, Mnemonic Devices, Visual supports, Metacognition, Code-switching & Translation

2) Research Articles

Etymology

Contradictory Definitions (Colloquial vs Scientific Language)

Metacognitive and other Linguistic Supports

Specialized Glossaries

Code-Switching

Appendix of Supplemental Materials for Module Kit #4

**Image #1:** Relationships and Breakups Cartoon for Elemental Personalities and Behavior

When a bond breaks up, the atoms exist in an unstable, high energy state. When a bond forms, the atoms exist in a stable, low energy state.

**Image #2:** Covalent versus Ionic Bonds Cartoon for Elemental Personalities and Behavior

**Image #3:** Polar versus Non-polar Bonds Cartoon for Elemental Personalities and Behavior
**Image #4:** Forming a Bond Cartoon for Elemental Personalities and Behavior

![Image](image4.png)

**Image #5:** Multiple Bonds Cartoon for Elemental Personalities and Behavior

<table>
<thead>
<tr>
<th>Covalent Bonding</th>
<th>Ionic Bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Double</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Triple</strong></td>
<td></td>
</tr>
</tbody>
</table>

*In solution: Example H₂O*
Image #6: Multiple Bonds Cartoon for Elemental Personalities and Behavior
**Worksheet #1: Bond Energy Inquiry for Bond Strength Versus Bond Energy**

**Bond Energy Inquiry Activity**

**Directions:** Individually observe the two reaction examples in Part I and Part II. Order is not necessarily important. Record your observations in the tables below. Analyze your data by comparing Part I observations with Part II observations. Construct a hypothesis for the prompt that is supported by your observations. Form groups of ~4 and share your proposed hypotheses. Explain your reasoning for your hypotheses. Evaluate the accuracy, consistency, and reasonability of each hypothesis. As a group, reconstruct a new and improved hypothesis!

### Part I: Water Splitting

Go to a station with a plastic cup of water & a 9-volt battery. Place the prongs of the 9-volt battery against the two metal tacks in the bottom of the cup. Observe and record results.

### Part I: Water Formation

Watch the video on the smart board closely and carefully. It will be played on repeat and shown in slow motion. Record your observations.

<table>
<thead>
<tr>
<th>Description: State what evidence showed that a reaction occurred?</th>
<th>Part I: Water Splitting</th>
<th>Part II: Water Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>In this reaction, what chemicals are the...</td>
<td>Reactants? (what you start with)</td>
<td>Products? (what you end up with)</td>
</tr>
<tr>
<td>Based on the reactants &amp; products, were bonds...</td>
<td>Made?</td>
<td>Broken?</td>
</tr>
<tr>
<td><strong>Energy:</strong> What type did you observe?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did Energy...</td>
<td>Enter the system?</td>
<td>Leave the system?</td>
</tr>
</tbody>
</table>
**Prompt:** Propose how energy behaves during a reaction (when bonds are broken &/or formed).
- When a bond is broken, is energy released or absorbed?
- When a bond is formed is energy released or absorbed?

**Construct your Hypothesis!**
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

What other Hypotheses did your group members propose?

**Evaluation:** Are they reasonable? Faulty? Why?

- 

- 

- 

**Construct a new, improved Hypothesis with your group!**
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Answer Key for Bond Energy Inquiry

Electrolysis of water versus Formation of water
\[ \text{e}^- \quad \Delta \]

\[ \text{H-O-H } \rightleftharpoons \text{H} + \text{O} \quad \Delta \text{H} = +571 \text{ kJ/mol} \]
\[ \text{H} + \text{O} \rightleftharpoons \text{H-O-H} \quad \Delta \text{H} = -571 \text{ kJ/mol} \]

Note: NOT Balanced!!!

1) Electrolysis of water
Need: Plastic cups, 9-volt batteries, baking soda, water

2) Formation of water (Hydrogen fuel cell)
VIDEOS
-https://www.youtube.com/watch?v=279r9QQDJm8 (rocket)
-https://www.youtube.com/watch?v=imV_uflZxPY (fuel cell visualization)
Worksheet #2: Graphic Organizer for Octet Rule Breakers

Bonding according to the Octet Rule... and Octet Rule-Breakers!

Directions: For each electron configuration, determine the identity of each element and draw the Lewis Dot diagram. Based on the electronegativity and number of valence electrons, determine how many bonds each element can make and whether those bonds will be based on giving, taking or sharing electrons. Be careful! Some elements have more than one answer... They're Octet Rule-Breakers! Tsk tsk tsk.

<table>
<thead>
<tr>
<th>Electron Configuration</th>
<th>Draw the Lewis Dot Structure</th>
<th>Write the electronegativity value</th>
<th>How many bonds can this element make?</th>
<th>Can this element give, take and/or share electrons when bonding?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1s² 2s² 2p⁶ 3s² 3p²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p⁶ 3s² 3p³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p⁶ 3s² 3p⁴</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p⁶ 3s² 3p¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p⁵</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p⁴</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p³ 3s² 3p³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1s² 2s² 2p¹ 3s² 3p³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Worksheet #3: Graphic Organizer for Determining Bond Type with Multiple Models

Using Molecular Models to Distinguish between Polar and Nonpolar Molecules

Name: ________________________________________  Date: __________________________
   Period: __________

Many properties of compounds (pure substances) are associated with the bonding of atoms. Some substances are soluble in water, while others are not. Some substances melt at low temperatures, others have high melting points. Some conduct electricity, others do not. Water, for example, has an unusually high boiling point in comparison to similar compounds.

In 1874, J. H. van ’t Hoff (1901 Nobel Prize in Chemistry) was the first to suggest that molecules have a three-dimensional structure. He used this idea to explain several previously puzzling facts about chemical compounds.

The interaction of molecules, which affect the physical properties (noted above) of a substance, is related to:
   1. Whether the bonds are polar or nonpolar covalent
   2. The shape of the molecule: linear, tetrahedral, pyramidal, bent

In this lab, we will use a kit to model the 3D structure of a number of molecules, including several that van ’t Hoff focused on. After building the molecular models, you will draw them on paper in a manner intended to represent the 3D appearance. You will also draw Lewis structures for some of the molecules as well as isomeric structures for those formulas that have them.

In this activity you will make three dimensional models of various molecules so that you can visualize their shapes. You will distinguish between four molecular shapes: linear, tetrahedral, pyramidal, and bent. You will identify the bonds in the molecule as polar or nonpolar. Based upon their bond type and shape, you will determine if the molecules are polar or nonpolar. Polar molecules dissolve in water and conduct electricity, whereas nonpolar ones generally do not.

Procedure: Using the molecular models kit, complete the following:
1. Make a Lewis dot structure of the molecule
2. Build the molecule
   a. The atoms are color coded:
      black = carbon
      yellow = hydrogen
      red = oxygen and other family members
      blue = nitrogen
      green = halogen atoms
b. Use the shortest wooden pegs to show single bonds. To show double or triple bonds, use springs instead of pegs. All the springs between two atoms should be the same length.

3.) Make a neat three-dimensional sketch of the molecule. Identify the shape of the molecule. The information list below may help you determine shape:

<table>
<thead>
<tr>
<th>Number of atoms</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Linear</td>
</tr>
<tr>
<td>3</td>
<td>Linear or bent</td>
</tr>
<tr>
<td>4</td>
<td>Pyramidal</td>
</tr>
<tr>
<td>5</td>
<td>Tetrahedral</td>
</tr>
</tbody>
</table>

4. Complete the tables
   a. Identify the bond type as polar or nonpolar based upon the electronegativity differences in your regents reference tables.
   b. Finally, identify the molecule as POLAR of NONPOLAR.

**Post-Lab Questions:**

1.) Are all compounds with polar bonds made up of polar molecules? Give 2 examples from this lab to explain your answer.

2. Distinguish between the different properties of polar molecules and nonpolar molecules.
### Template for Associated Graphic Organizer

<table>
<thead>
<tr>
<th>Formula</th>
<th>H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
</tr>
<tr>
<td>Lewis Dot Structure</td>
<td></td>
</tr>
<tr>
<td>Bond type based upon electronegativity difference (polar bond or nonpolar bond)</td>
<td></td>
</tr>
<tr>
<td>Three-dimensional drawing of molecule. (What the model you made looks like)</td>
<td></td>
</tr>
<tr>
<td>Shape of molecule (linear, bent, pyramidal, tetrahedral)</td>
<td></td>
</tr>
<tr>
<td>Type of molecule (polar molecule or nonpolar molecule)</td>
<td></td>
</tr>
</tbody>
</table>

Examples of Other Suggested Molecular Formulas:
- HCl
- H₂O
- H₂S
- NH₃
- HOCl
- O₂
- N₂
- CH₄
- CHCl₃
- CO₂
- HCN
Module-specific Glossary #1: Etymology of Bonding Terms

Etymological Glossary for Module #4

able  | See uble
al   | (Latin) Related to  | Ex: Trigonal
aqua | (Latin) Water       | Ex: Aqueous
ar   | (Latin) Pertaining to | Ex: Polar
ate  | (Latin) To act by [verb] or to be like [adjective] | Ex: Coordinate
co   | See con
con  | (Latin) Together or to the same degree | Ex: Covalent
dis  | (Latin) Apart       | Ex: Dispersion
duct | (Latin) To lead      | Ex: Conduction
ent  | (Latin) To be        | Ex: Covalent
gon  | (Greek) Angle        | Ex: Trigonal
hedron | (Greek) Face or Plane | Ex: Tetrahedron
ible | See uble
ic   | (Latin) Pertaining to | Ex: Polyatomic
inter| (Latin) Between      | Ex: Intermolecular
intra| (Latin) Within       | Ex: Intermolecular
ion  | (Latin) State or action of | Ex: Conduction
ity  | (Latin) Having the quality or condition of | Ex: Conductivity, Solubility
ive  | (Latin) Tends to or has the nature of | Ex: Conductive, Electronegative
metry| (Latin) Measure      | Ex: Symmetry
negat| (Latin) To deny      | Ex: Electronegative
non  | (Latin) Not          | Ex: Non-polar
ordin| (Latin) Order        | Ex: Coordinate
ous  | (Old English) Having the nature of | Ex: Aqueous
per  | (Latin) Thoroughly or through the means of | Ex: Dispersion
pol  | (Latin) Pole or the end of an axis | Ex: Polar
poly | (Greek) Many         | Ex: Polyatomic ion
posit| (Latin) Place        | Ex: Electropositive
pyramid| (Latin) Pyramid-shape | Ex: Pyramidal
sol  | (Latin) To loosen    | Ex: Soluble
solu | See sol             
solv | See sol             
sym  | (Latin) Same         | Ex: Symmetry
tetra| (Latin) Four         | Ex: Tetrahedron
tri  | (Latin) Three        | Ex: Trigonal
uble | (Latin) Able to      | Ex: Soluble
## Examples of Etymological Analysis

<table>
<thead>
<tr>
<th>Word</th>
<th>Etymology</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueous</td>
<td>aqu(a) + ous</td>
<td>Having the nature of water</td>
</tr>
<tr>
<td>Conduction</td>
<td>con + duct + ion</td>
<td>The act of (electrons) being lead together</td>
</tr>
<tr>
<td>Conductivity</td>
<td>con + duct + iv(e) + ity</td>
<td><strong>Having the quality of</strong> (electrons) being lead together</td>
</tr>
<tr>
<td>Coordinate</td>
<td>co + ordin + ate</td>
<td>The act of (electrons) being ordered together</td>
</tr>
<tr>
<td>Covalent</td>
<td>co + val(en) + ent</td>
<td>To be powerful to the same degree</td>
</tr>
<tr>
<td>Dispersion</td>
<td>dis + per + ion</td>
<td>The state of being thoroughly apart</td>
</tr>
<tr>
<td>Electropositive</td>
<td>electr + posit + ive</td>
<td>Tending to put electrons (elsewhere)</td>
</tr>
<tr>
<td>Electronegativity</td>
<td>electr + negat + iv(e) + ity</td>
<td>The tendency to deny electrons (from being taken)</td>
</tr>
<tr>
<td>CLUE! Atoms that deny other atoms access to their electrons (prefer to keep them!)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermolecular</td>
<td>inter + molecul(e) + ar</td>
<td>Pertaining to (electrons) between molecules</td>
</tr>
<tr>
<td>Intra(molecular)</td>
<td>intra + molecul(e) + ar</td>
<td>Pertaining to (electrons) within molecules</td>
</tr>
<tr>
<td>Non-polar</td>
<td>non + pol + ar</td>
<td>Not pertaining to having a (magnetic) pole</td>
</tr>
<tr>
<td>Polar</td>
<td>pol + ar</td>
<td>Pertaining to having a (magnetic) pole</td>
</tr>
<tr>
<td>Polyatomic</td>
<td>poly + atom + ic</td>
<td>Pertaining to have many atoms</td>
</tr>
<tr>
<td>Pyramidal</td>
<td>pyramid + al</td>
<td>Related to a pyramid</td>
</tr>
<tr>
<td>Solubility</td>
<td>sol + uble + ity</td>
<td>Having the ability to loosen</td>
</tr>
<tr>
<td>Soluble</td>
<td>sol + uble</td>
<td>Able to loosen</td>
</tr>
<tr>
<td>Symmetry</td>
<td>sym + metry</td>
<td>Same measure</td>
</tr>
<tr>
<td>Tetrahedral</td>
<td>tetra + hedron</td>
<td>(Shape with) Four planes</td>
</tr>
<tr>
<td>Trigonal</td>
<td>tri + gon + al</td>
<td>Related to three angles</td>
</tr>
</tbody>
</table>
Module-specific Glossary #2: Vocabulary of Bonding Types

Vocabulary Glossary for Module #4

Aqueous
A solution in which water is the solvent
(Translation) A mixture in which a substance is dissolved in water

Note: Compare to Solubility

Bent
A molecular shape, in which the central atom has two substituents that are approximately 105° apart and one or two lone pairs of electrons.

Note: Refer to Molecular Geometry

Note: Compare to Linear, Tetrahedral and Trigonal Pyramidal

Bond
The attraction between atoms that holds molecules together, which results from electron interactions, such as sharing or transferring.
(Translation) When two atoms share or trade electrons, which causes the atoms to stick together

Bond Strength
A measure of how difficult it is to break a chemical bond, which is directly related to how much energy is required to break the bond.
(Translation) A strong bond is very stable, exists in a low energy state, and thus requires a lot of energy to break. A weak bond is not stable, exists in a higher energy state and thus does not require much energy to break.

Note: Refer to Bond

Conductivity
A property of a substance that is able to transfer electricity through itself

Coordinate
A type of covalent bond, in which the two shared electrons originated from only one atom in the bond.
(Translation) A bond made when one atom contributes two electrons to be shared between itself and another atom

Note: Refer to Bond

Note: Compare to Covalent Bond

Covalent
A type of bond, in which two atoms share their electrons

Note: Refer to Bond

Note: Compare to Ionic Bond

Dipole
A molecule that has both a partial positive and partial negative charge, usually due to electronegative atoms affecting the distribution of electrons

Note: Refer to Electronegativity

Dispersion Forces
The weakest type of intermolecular force, in which the attraction arises from temporary induced dipoles. Also known as London Forces
(Translation) A force of intermolecular attraction that occurs by chance when random electron movement creates one momentary dipole, which causes a chain effect of temporary dipoles among neighboring molecules

Note: Refer to Intermolecular Forces and Dipoles
Double Bond
A type of covalent bond, in which two atoms share four electrons

Note: Compare to Van Der Waals Forces
Note: Refer to Covalent Bond
Note: Compare to Single Bond and Triple Bond

Electronegativity
A property of an atom based on its ability to attract electrons, which determines what type of bonds the atom can form. Sometimes used interchangeably with the term electron affinity. (Translation) A measure of an atom's ability to attract electrons to itself

Note: Compare to Electropositivity

Electropositivity
A property of an atom based on its ability to donate electrons, which determines what types of bonds the atom can form. The inverse property of electronegativity

(Translation) The opposite of electronegativity. A measure of an atom's ability to give away its electrons

Note: Compare to Electropositivity

Hydrogen Bonding
A very strong intermolecular force, which is a dipole-dipole interaction between molecules that have a hydrogen attached to a highly electronegative atom, such as oxygen or nitrogen.

Note: Refer to Intermolecular Force, Electronegativity and Dipole

Intermolecular Forces
An attraction or repulsion between molecules, which are much weaker than bonds, such as hydrogen bonds, dispersion and Van der Waals forces.

Note: Refer to Hydrogen Bond, Dispersion Forces and Van der Waals Forces

Note: Compare to Intramolecular Forces

Intramolecular Forces
An attraction within molecules that holds the atoms of that molecule together.

(Translation) A chemical bond.

Note: Refer to Bond
Note: Compare to Intermolecular Forces

Ionic
A type of bond, in which electrons are transferred from one atom to another, which results in opposite charges that attract

Note: Refer to Bond
Note: Compare to Covalent Bond

Linear
A molecular shape, in which the central atom has two substituents that are 180° apart and no lone pairs of electrons.

Note: Refer to Molecular Geometry
Note: Compare to Bent, Tetrahedral and Trigonal Pyramidal

Lone Pair Electrons
A pair of electrons on an atom that are not involved in bonding.

Metallic
A type of bond, in which electrons migrate across a lattice of positively charged ions
(Translation) The attraction between an orderly arrangement of positively charged ions and a sea of mobile electrons

**Note:** Refer to *Bond*  
**Note:** Compare to *Covalent Bond* and *Ionic Bond*

**Molecular Geometry**  
The three dimensional shape of a molecule, based on the arrangement of atoms around a central atom.  

**Note:** Compare to *Molecular Symmetry*

**Molecular Symmetry**  
A quality of molecular geometry, which predicts molecular polarity.  

(Translation) Whether a molecule is symmetrical or asymmetrical, which determines whether the molecule is non-polar or polar  

**Note:** Refer to *Molecular Geometry* and *Polarity*

**Molecule**  
An uncharged group of atoms held together by covalent chemical bonds  

**Network Covalent Solid**  
A type of molecule, in which all atoms are covalently bonded together in a rigid, repeating structure.  

**Non-polar**  
A type of covalent bond, in which two atoms share their electrons almost equally resulting in a symmetrical distribution of electrons  

**Note:** Refer to *Covalent Bond*  
**Note:** Compare to *Polar*

**Polar**  
A type of covalent bond, in which two atoms share their electrons unequally, which results in an asymmetrical distribution of electrons. Sometimes considered an intermediate between non-polar covalent and ionic bonding. Can also refer to a polar molecule, which is a molecule with asymmetrical geometry and thus asymmetrical electron distribution.  

**Note:** Refer to *Covalent Bond*, and *Ionic Bond*  
**Note:** Compare to *Non-polar*

**Polarity**  
A property of a molecule or a bond, which depends on the distribution of electrons.  

(Translation) For bonds, a property that depends on the distribution of electrons as determined by the electronegativity of the two atoms. For molecules, a property that depends on the distribution of electrons due to both molecular symmetry overall and electronegativity of the individual atoms within the molecule.  

**Note:** Refer to *Electronegativity* and *Molecular Symmetry*  
**Note:** Compare to *Non-polar* and *Polar*

**Polyatomic Ion**  
A molecule of two or more covalently bonded atoms that carries a charge.  

**Note:** Compare to *Ion*

**Resonance**  
The bonding behavior of a molecule that cannot be accurately or completely described with only one Lewis Structure, due to the existence of delocalized electrons within that molecule.
(Translation) The true state of the bonding behavior of a molecule, in which electrons do not form one discrete bond between two atoms, but exist as multiple partial bonds between two or more atoms.

**Note:** Refer to *Lewis Structure*

**Single Bond**
A type of covalent bond, in which two atoms share two electrons.

**Note:** Refer to *Covalent Bond*

**Note:** Compare to *Double Bond* and *Triple Bond*

**Solubility**
The ability of a substance, called the solute, to dissolve in a solvent to form a homogeneous solution.

**Tetrahedral**
A molecular shape, in which the central atom has four substituents that are approximately 109° apart and no lone pairs of electrons.

**Note:** Refer to *Molecular Geometry*

**Note:** Compare to *Bent, Linear* and *Trigonal Pyramidal*

**Trigonal Pyramidal**
A molecular shape, in which the central atom has three substituents that are approximately 109° apart and one lone pair of electrons.

**Note:** Refer to *Molecular Geometry*

**Note:** Compare to *Bent, Linear* and *Trigonal Pyramidal*

**Triple Bond**
A type of covalent bond, in which two atoms share six electrons.

**Note:** Refer to *Covalent Bond*

**Note:** Compare to *Single Bond* and *Triple Bond*

**Van Der Waals Forces**
A type of intermolecular force, that results from the movement of electrons. Includes dispersion forces and dipole-dipole interactions.

**Note:** Refer to *Intermolecular Forces* and *Dipoles*

**Note:** Compare to *Dispersion Forces*
Module-specific Glossary #3: Symbols of Bonding Models

Symbol Glossary for Module #4

*Singular Symbols*

: Lone pair of electrons found in Lewis dot diagrams. Also called non-bonding electrons

_ Indicates a single bond between atoms in Lewis dot diagrams or line-angle chemical structures (sometimes called skeletal).

= Indicates a double bond between atoms in Lewis dot diagrams or line-angle chemical structures (sometimes called skeletal).

≡ Indicates a triple bond between atoms in Lewis dot diagrams or line-angle chemical structures (sometimes called skeletal).

*Types of Symbol Notation*

**Line-angle Structure**  
A diagram of a molecule that depicts bonds with lines and atoms with their elemental symbol. Also are called skeletal structures, and can be derived from Lewis Dot Structures

(3)

(Looks like)

H—O—H
## Module Kit #5

**College at Brockport, Department of Education & Human Development**

**Linguistic Strategies for Chemistry - Module #5**

Designed by Genevieve Criss

### Associated Chemistry Unit:
- Unit #5: Compounds

### Unit Subject or Content area:
- Molecular Formulas of Ionic & Covalent Compounds

### Module Title:
- Writing and Reading Chemical Words: Molecular Formulas & Chemical Structural Depictions

### Module Overview

**Provide a narrative that explains what language needs this module supports and why it is relevant?** The fifth unit of chemistry focuses on the primary building block necessary to write chemical equations: the form of chemical compounds, which are the equivalent of chemical words. Using knowledge from Units #2 & #3 & #4, the number of atoms needed to form a neutral compound, as well as the type of compound and molecular geometry can be determined from electronegativity, electron configuration and other factors. Additionally, this unit highlights the three major dialects of chemical language; formulas, structures and nomenclature, each of which students must be able to master. In the next unit, students will further combine compounds into chemical equations to describe chemical reactions, which is an action parallel to writing full sentences.

The central learning objective here is for students to be able to depict simple compounds. However, these compounds can be represented in any of three dialects. Additionally, students should be able to translate between the dialects of formulas, structures and nomenclature. Each dialect requires specific heuristic activities and other supports, ranging from etymological to metacognitive strategies.

For Molecular Formulas, students must be able to correctly identify the atomic symbols and then combine them in a way that produces a neutral compound according to oxidation state. The 'alphabet soup' here benefits most from the symbolic glossary.

For IUPAC Nomenclature, students must be able to correctly write the chemical name, according to the relevant nomenclature system (ionic or organic). These complicated wording systems benefit most from detailed explanation of the nomenclature system, with explicit focus on etymological word stems used in chemical nomenclature.

Molecular Structures was largely covered in Unit #4, however review during this unit would be suggested.

Overall, this unit provides students with their primary 'vocabulary' in chemical language; the identify of compounds. Once students have mastered their ability to determine the identity of compounds and depict them in various dialects, they will be prepared for the next unit, in which they will progress to applying molecular formulas to the creation of chemical equations, the equivalent of chemical sentences.

### Module Objective(s):

**Develop an objective statement that aligns with the language needs and uses observable and measurable goals.** The primary goal of this module is develop student ability to write, read and otherwise analyze Molecular Formulas and IUPAC Nomenclature of simple compounds, which demonstrates a mastery over molecular forms. This skills are crucial for students to be able to advance to writing chemical equations. Specific objectives are:

- When provided with two (or more) elements and asked to write the chemical formula of what compound they would form, students will be able to accurately write the Molecular Formula of the neutral compound with the use of the periodic table and Tables E & S as needed.
- When provided with two (or more) elements and asked to write the chemical name in IUPAC
nomenclature of what compound they would form, students will be able to accurately write the IUPAC name of the natural compound (including oxidation states if required) with the use of the periodic table and Tables E & S as needed.

- Additionally, students must be able to write IUPAC nomenclature for ionic compounds with ionic nomenclature and covalent compounds with organic nomenclature.
- When provided a molecular formula and asked to name it according to IUPAC nomenclature, students will be able to accurately write the IUPAC Name of the compound (including oxidation states if required) with the use of the periodic table and Tables E & S as needed.
- When provided with the IUPAC name of a compound and asked to write the molecular formula, students will be able to accurately write the Molecular Formula of the natural compound (including accuracy with the oxidation state, if present) with the use of the periodic table and Tables E & S as needed.
- When provided with a molecular formula or IUPAC name of a binary compound and asked to draw the Lewis structure of the compound, students will be able to correctly depict said compound in regards to both bonds and molecular geometry with the use of the periodic table and Table S as needed.
- When provided with a Lewis dot structure of a compound and asked to write or depict the molecular formula or IUPAC name of a compound, students will be able to accurately write the molecular formula or IUPAC name with the use of the periodic table and Table S as needed.

### Content Outline

1) Knowledge
- Etymology  IUPAC Nomenclature prefixes and suffixes
- Symbols  Molecular Formulas, Structural Models
- Vocabulary  Compound, Pure Substance, Formula, Binary Compounds, IUPAC Nomenclature, Oxidation State

2) Skills
- Ability to...  Read and write Molecular Formulas for simple compounds
- Ability to...  Read and write IUPAC Nomenclature for simple compounds
- Ability to...  Translate between Molecular Formulas, IUPAC Nomenclature and Structural Models

3) Values
- Demonstrate...  Recognition of the dialectic nature of Chemical Language as demonstrated by IUPAC nomenclature, Molecular Formulas and Structural Depictions

### Activities and Instructional Strategies

1) Challenge:  Differentiation of Paired/Related Concepts
Applicable to:  Oxidation State vs Charge, IUPAC Nomenclature vs common names, States of Matter (Compounds, Elements, Pure Substances, etc.)

Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation</td>
<td>Using Molecular</td>
<td>Explain or discuss the differences in the vocabulary terms</td>
</tr>
<tr>
<td>State vs Charge</td>
<td>Models to Show Electron 'Ownership'</td>
<td>using molecular models as visual support. Particularly clarify the difference between oxidation state and charge for ionic versus covalent compounds. Use color coding in the molecular models to demonstrate &quot;ownership&quot; of the electrons. Graphic organizers can also be utilized.</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IUPAC Nomenclature vs common names</td>
<td>Analysis of IUPAC prefixes and suffixes</td>
<td>Using the etymological glossary as a reference, explicitly demonstrate the metacognitive process to analyze the morphemes within IUPAC nomenclature to ascertain their meaning. Common names often has etymological foundations as well, however they are not the same roots that IUPAC names systematically follow. This process is also known as decoding. (See Glossary #1 in Supplemental Materials Appendix for Module #5; See Etymology Glossary in Supplemental Materials Appendix for all Modules)</td>
</tr>
<tr>
<td>States of Matter</td>
<td>States of Matter Hierarchy</td>
<td>Provide students with a blank graphic organizer that is depicts a heirarchal format for students to fill in with the various forms of matter and their definitions in order to demonstrate relationships and key differences. This graphic organizer can also be expanded to demonstrate the 'dialects' of chemistry using Frayer models, that show the linguistic definition, and multiple physical depictions of an example in formula, nomenclature and structural form. (See Image #1 in Supplemental Materials Appendix for Module #5; originally retrieved from <a href="http://derekpunterscience7.weebly.com/uploads/1/3/8/7/13878391/3994827.jpg?868">http://derekpunterscience7.weebly.com/uploads/1/3/8/7/13878391/3994827.jpg?868</a>)</td>
</tr>
</tbody>
</table>

2) Challenge: Differentiation of Scientific & Colloquial Meanings  
Applicable to: Formula  
Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>The Secret Formula</td>
<td>Formula has multiple definitions colloquially, which one is very applicable and similar to the chemical meaning. The applicable colloquial definition should be highlighted and separated from less applicable colloquial definitions, such as the mathematical formula. In particular, the analogy of a for example a soda formula can work well, by drawing parallels between the ingredients in a soda formula and the atoms in a chemical formula.</td>
</tr>
</tbody>
</table>

3) Challenge: Decoding & Encoding Molecular Formulas  
Applicable to: Any Molecular Formula, including Binary and Polyatomic compounds  
Possible Activities

- Chemical Formula Poker or Gin Rummy - Each card in this card game has one atomic symbol on
it. Students must combine the atomic symbols in their hand into neutral compounds either following the rules of Poker or Gin Rummy. This game provides practice for balancing charges and recognizing compounds. Additionally, it provides students a simplified depiction of a molecular formula (Ex: MnCl₂ would appear as Mn Cl Cl in this card game). (See Image #2 and Worksheet #1 in Supplemental Materials Appendix for Module #5; Examples of game cards originally from retrieved http://www.ellenjmchenry.com/homeschool-freedownloads/chemistry-games/documents/QuickSix_12_11_000.pdf)

- **Cut and Paste Reference Posters** - On the students Regents Reference packet show students how to mark, highlight and cut and paste pieces from the periodic Table and Tables E & S onto a poster in ways that support their use of the table in the compilation of Molecular formulas. In particular, demonstrate how the name of an element can be found on Table S, and used to find the atomic symbol, as well as the oxidation states. Students are encouraged to develop their own preferred marking systems, which should support student navigation and application of the Periodic Table or Table S. As needed, provide the students with extra support such as the student tips for Regents References packet.

- **Side Note Molecular Formulas Key** - In the student notes packets, place a glossary box in the margins that defines the new symbols. Using the Periodic table and symbol glossary as a reference, explicitly demonstrate the metacognitive process to analyze the individual symbols within the molecular formula in order to name compounds, balance the charges, or devise compounds. For example, the meaning behind the positions of numbers in molecular formulas, such as superscripts and subscripts, should be explicitly explained. Specifically, each atomic symbol should be labeled, and if possible step-wise instructions that explain how the formula was compiled from information from the periodic table. In particular, this heuristic method should be used to demonstrate tricks, such as the criss-cross method, which is used to determine the subscripts in molecular formulas. Further, comparisons of different molecular formulas with labeled symbols can be provided. Alternatively, an entire symbol glossary can be provided. (See Glossary #3 in Supplemental Materials Appendix for Module #5; See Symbol Glossary in Supplemental Materials Appendix for all Modules)

4) **Challenge: Decoding & Encoding IUPAC Nomenclature**

   **Applicable to:** Binary compounds or compounds with a polyatomic ion from Table E

   **Possible Activities**

   - **Extrapolation/Continuation from Cut & Paste Reference Posters in Challenge #3 Above** - Cut and Paste Reference Posters (above) cover decoding and encoding support for Molecular Formulas from the Regents Reference Packet. Strategies used there can be reviewed and then expanded upon to demonstrate how to adjust those heuristic strategies and support use of the Periodic table in the compilation of IUPAC names of compounds. In particular, demonstrate how the name of an element can be found on Table S from the atomic symbol. Students are encouraged to develop their own preferred marking systems, which should support student navigation and application of the Periodic Table or Table S. As needed, provide the students with extra support such as the student tips for Regents References packet.

   - **Side note IUPAC Nomenclature Key** - In the student notes packets, place a glossary box in the margins that defines the new symbols and etymological word stems used in IUPAC nomenclature. Using the Periodic table and etymology glossary as a reference, explicitly demonstrate the metacognitive process to analyze the individual parts of a within a chemical name in order to write or identify the name of a chemical compound. For example, the meaning
behind the roman numerals and the IUPAC prefixes and suffixes should be explicitly explained. Specifically, each word stem should be labeled, and if possible step-wise instructions that explain how the chemical name was compiled from information from the periodic table and Table E & S. In particular, this heuristic method should focus on the etymology & systematic naming rules, which are used to determine chemical nomenclature. Further, comparisons of different IUPAC names with labeled prefixes, suffixes and symbols can be provided. Alternatively, an entire etymological and symbol glossary can be provided. (See Glossary #1 in Supplemental Materials Appendix for Module #5; See Etymology Glossary in Supplemental Materials Appendix for all Modules)

5) Challenge: Translation between Molecular Formulas, IUPAC Nomenclature & Structural Models
   Applicable to: Molecular formulas and IUPAC Nomenclature (as described above), Structural Models (as described in Module #4)
   • Extrapolation/Continuation from Challenge #3 & #4 Above - Challenge #3 & #4 in Unit #5 (above) cover Decoding, Encoding Molecular Formulas and IUPAC Nomenclature. Strategies used there can be reviewed and then expanded upon to demonstrate how to adjust those heuristic strategies and supports to translation between the 'dialects' of chemical words.
   • Different Depictions - Same Compound: Chemical compounds can be depicted or represented with Molecular Formulas, IUPAC Nomenclature or Structural Models. Therefore to demonstrate their equivalency, students could be given a graphic organizer, within which to write the formula, name and draw the structure of examples of chemical compounds.
   • Foolish Formulas - Provide students with a worksheet that only has incorrect answers for translation challenges between Molecular formulas and IUPAC nomenclature. Challenge the students to determine the correct answers and to determine why the original foolish answers were incorrect. (See Worksheet #2 in Supplemental Materials Appendix for Module #5)

**Instructional Resources and Materials to engage students in learning:**

1) Module Specific: See Supplemental Materials Appendix for Module #5 Below
   Images
   • **Image #1**: Graphic Organizer for States of Matter Hierarchy
   • **Image #2**: Example Game Cards for Formula Poker or Gin Rummy
   Worksheets
   • **Worksheet #1**: Rules for Formula Poker or Gin Rummy
   • **Worksheet #2**: Quiz for Foolish Formulas
   Module Specific Glossaries
   • **Glossary #1**: Etymology of IUPAC Nomenclature
   • **Glossary #2**: Vocabulary of Compound Terms
   • **Glossary #3**: Symbols of Molecular Formulas

2) General: See Supplemental Materials Appendix for all Modules
   Glossaries
   • **Glossary #1a**: Etymology Glossary for Scientific Terminology & Concepts
   • **Glossary #1b**: Etymological Glossary for IUPAC Nomenclature terminology
   • **Glossary #2**: Vocabulary Glossary for Scientific Concepts and Terminology
   • **Glossary #3**: Symbol Glossary for Mathematic and Chemical Symbols
<table>
<thead>
<tr>
<th>Regents Reference Tables Supports</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regents Reference Table Support #1</strong>: Links for Navigating Regents Reference Tables</td>
</tr>
<tr>
<td><strong>Regents Reference Table Support #2</strong>: Link to Interactive Online Periodic Table</td>
</tr>
<tr>
<td><strong>Regents Reference Table Support #3</strong>: Etymological Analysis of Elemental Names</td>
</tr>
</tbody>
</table>
Relevant theories and/or research best practices:

What theories and scholarly sources ground your decisions about the learning tasks?

1) General Theories
   - Linguistic Etymology, Specialized Glossaries, Mnemonic Devices, Visual supports, Metacognition, Code-switching & Translation

2) Research Articles

   Etymology

   Contradictory Definitions (Colloquial vs Scientific Language)

   Metacognitive and other Linguistic Supports

   Specialized Glossaries

   Code-Switching

Appendix of Supplemental Materials for Module #5

**Image #1:** Graphic Organizer for States of Matter Hierarchy

**Image #2:** Example Game Cards for Formula Poker or Gin Rummy
Worksheet #1: Rules for Formula Poker or Gin Rummy

Chemical Formula Poker

Materials: Each deck should contain approximately 90 cards. There are 4 kinds of cards, Metal Cation cards, Polyatomic Ion cards, Non-metal Anion cards and wild cards. Each card (except wild cards) has a proper name written on it. It is your job to determine the charge! Also, the closer the charge is to zero, the more duplicates there are in the deck.

Metal Cation Cards
Charge ranges from +1 to +4.

Non-metal Anion Cards
Charge ranges from -1 to -4.

Polyatomic Ion Cards
Charge ranges from +1 to -3.

Wild Cards
Charge ranges from +4 to -4. Some wild cards are charge, cation or anion specific.

Goal: To compile cards into sets of ionic formulas. The more cards used (out of your hand of 5) the more likely you are to win the round.

Game Play

1. First Rotation*: The dealer will pass out 5 cards to each player from the shuffled deck, placing all remaining cards in a central stack.
2. Second Rotation*: Starting with the player to the right of the dealer, each player may discard up to 3 cards from their hand and replace them with the same number of cards from the draw pile.
3. Third Rotation*: Starting with the player to the right of the dealer, each player may discard up to 2 cards from their hand and replace them with the same number of cards from the draw pile.
4. Reveal: Starting with the player to the right of the dealer, each player will show their hand, and state the proper ionic name of each compound they compiled. If the player was unable to make a complete (neutral) compound, they may pass (aka fold). The player with the highest ranking formula set wins the round. To determine ranking, see the "Formula sets/Hands table".
5. After each reveal, start a new rotation. Have fun!

Formula Rules

Each formula must contain one type of cation card, one type of anion card and have an overall neutral charge!!!

For example: $\text{Na}^+\text{O}^{2-}$ NOT Acceptable: Not neutral
$\text{Na}^+\text{Li}^+\text{O}^{2-}$ NOT Acceptable: 2 types of cations
$\text{Na}^+\text{Na}^+\text{O}^{2-}$ Acceptable! Follows rules
**Formula Sets/Hands Table**

Note: The hand type or formula closest to the top is the highest ranking. Bottom is the lowest.

<table>
<thead>
<tr>
<th>Example</th>
<th>Card Examples</th>
<th>Formula Set</th>
<th>Number of Formula(s)</th>
<th># of unused cards</th>
<th>Type of Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li₄C or TiF₄</td>
<td>Li Li Li Li C <strong>or</strong> Ti F F F F</td>
<td>C₄A <strong>or</strong> CA₄</td>
<td>1</td>
<td>0 cards</td>
<td>1:4 Pentatomic Salt</td>
</tr>
<tr>
<td>Sc₂O₃ or Be₃N₂</td>
<td>Sc Sc O O O <strong>or</strong> Be Be Be N N</td>
<td>C₂A₃ <strong>or</strong> C₂A₂</td>
<td>1</td>
<td>0 cards</td>
<td>2:3 Pentatomic Salt</td>
</tr>
<tr>
<td>Li₃N or ScF₃</td>
<td>Li Li Li N ? <strong>or</strong> C₃A <strong>or</strong> CA₃</td>
<td></td>
<td>1</td>
<td>1 cards</td>
<td>1:3 Tetratomic Salt</td>
</tr>
<tr>
<td>LiF and LiF</td>
<td>Li Li F F ?</td>
<td>C₂A₂ (Actually Duplicate CA)</td>
<td>2 Identical</td>
<td>1 cards</td>
<td>1:1 Diatomic Salt Identical Pair</td>
</tr>
<tr>
<td>LiF and Na₂O or LiF and BeCl₂</td>
<td>Li F Na Na O <strong>or</strong> Li F Be Cl Cl</td>
<td>CA &amp; C₂A <strong>or</strong> CA &amp; CA₂</td>
<td>2</td>
<td>0 cards</td>
<td>1:1 Diatomic Salt &amp; 1:2 Triatomic Salt</td>
</tr>
<tr>
<td>Li₂O or BeF₂</td>
<td>Li Li O ??? <strong>or</strong> Be F F ??</td>
<td>C₂A <strong>or</strong> CA₂</td>
<td>1</td>
<td>2 cards</td>
<td>1:2 Triatomic Salt</td>
</tr>
<tr>
<td>LiH and NaF</td>
<td>Li H Na F ?</td>
<td>CA <strong>and</strong> CA</td>
<td>2 Different</td>
<td>1 cards</td>
<td>1:1 Diatomic Salt Pair</td>
</tr>
<tr>
<td>LiF</td>
<td>Li F ?? ?</td>
<td>CA</td>
<td>1</td>
<td>3 cards</td>
<td>1:1 Diatomic Salt</td>
</tr>
</tbody>
</table>

**Key for Card Examples:**
? = Unused card & Periodic Table Symbols

**Key for Formula Set:**
C = Cation (Metal or Polyatomic)  
A = Anion (Non-metal or Polyatomic)

**Note!** If two players have the same type of hand (Ex: Both have a 1:1 Diatomic Salt Hand, CA):

1. Compare the polyatomic ions. Whichever player has more polyatomic ions wins.
   a. Example: LiF versus LiCN
      LiF has 0 polyatomic ions
      LiCN has 1 polyatomic ion → LiCN wins

2. If same number of polyatomic ions, then add the absolute value of the individual charges. Whichever player has a greater number wins.
   a. Example: LiF versus BeO:
      Li & F = |+1| + |-1| = 2
      Be & O = |+2| + |-2| = 4 → BeO wins

3. If same absolute value, then compare the mass of the compounds in amu. Whichever player has a greater mass number wins.
   a. Example: LiF versus NaCl:
      b. Li & F = 7 amu + 19 amu = 26 amu total
      Na & Cl = 23 amu + 35 amu = 58 amu total → NaCl wins
BONDING GIN RUMMY RULES

The objective of Bonding Gin Rummy is to collect element cards into compounds (at least 3 elements bonded together) and have as few unbonded elements as possible at the end of each round. The game is scored at the end of each round, and is based on how many compounds you have formed with unbonded elements detracting points you earned. A game can span several rounds, it ends when a round ends with at least one player reaching 100 points or when class ends. At that point, the player with the highest score wins the whole game.

GAMEPLAY

- Each player begins with 10 element cards and one scorecard. The table should have one rule poster and at least one periodic table. The remaining element card deck is put on the table between the players face down, and one card is put face up beside the deck to start the discard pile.
- To start each turn, a player must start by drawing one element card. The player can either draw the top card from the deck or the top card from the discard pile.
- During their turn, a player will rearrange the element cards in their hand to form compounds. If the player can successfully form a compound, they may place it down on the table in front of them. Once a compound is put down, it cannot be returned to the hand. It will later be counted for points.
- After the player has drawn a card and placed down their compounds if they wish, to end their turn they must discard one card by putting it face up on top of the discard pile, covering the previous card, which can no longer be used.
- To end the round, a player must have placed down 10 element cards as compounds, so that they have one last element card to discard. All other players then have one last turn to complete as many compounds as possible and place them down.
- To score, each player will fill out a score card. The group will convene and each player will explain how many points they earned and why for each compound to ensure correct scoring.

SCORING: For each compound...

1. Formed with at least 3 elements? -1 pts for each element if no, STOP. If yes, go on.
2. Filled orbital rule satisfied? -1 pts for each element if not, STOP. If yes, go on.
3. Correctly identified as molecular? 0 pts if incorrectly identified, STOP.
   OR as non-molecular? +1 pts if correctly identified, go on through #10.
4. How many ionic bonds? ________ +1 pts for each ionic bond
5. How many covalent double bonds? ________ +1 pts for each double bond
6. How many covalent triple bonds? ________ +2 pts for each triple bond
7. How many polar covalent bonds? ________ +1 pts for each polar bond
8. How many non-polar covalent bonds? ________ +1 pts for each non-polar bond
9. Overall polarity is? ____________ +1 if correctly identified
10. Molecular geometry is? ____________ +1 if correctly identified
SCORE CARD

1. Formed with at least 3 elements? ___________ -1 pts for each element if not, STOP
   If yes, continue

2. Filled orbital rule satisfied? ___________ -1 pts for each element if not, STOP
   If yes, continue

3. Molecular or non-molecular? ___________ 0 pts if incorrectly identified, STOP
   +1 pts if correctly identified, go on

4. How many ionic bonds? ___________ +1 pts for each ionic bond

5. How many covalent double bonds? ___________ +1 pts for each double bond

6. How many covalent triple bonds? ___________ +2 pts for each triple bond

7. How many polar covalent bonds? ___________ +1 pts for each polar bond

8. How many non-polar covalent bonds? ___________ +1 pts for each non-polar bond

9. Overall polarity is? ___________ +1 if correctly identified

10. Molecular geometry is? ___________ +1 if correctly identified

<table>
<thead>
<tr>
<th></th>
<th>Round #1</th>
<th>Round #2</th>
<th>Round #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compound A pts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compound B pts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compound C pts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- pts for unbonded elements

Total pts for Round

Overall Total pts
**EXAMPLE SCORE CARD**

1. Formed with at least 3 elements? -1 pts for each element if not, STOP
   If yes, continue
2. Filled orbital rule satisfied? -1 pts for each element if not, STOP
   If yes, continue
3. Molecular or non-molecular? ______________ 0 pts if incorrectly identified, STOP
   +1 pts if correctly identified, go on
4. How many ionic bonds? ___________ +1 pts for each ionic bond
5. How many covalent double bonds? ___________ +1 pts for each double bond
6. How many covalent triple bonds? ___________ +2 pts for each triple bond
7. How many polar covalent bonds? ___________ +1 pts for each polar bond
8. How many non-polar covalent bonds? ___________ +1 pts for each non-polar bond
9. Overall polarity is? ______________ +1 if correctly identified
10. Molecular geometry is? ______________ +1 if correctly identified

Unknown is acceptable for geometry, because you have only learned 4 of the many, many geometrical shapes

Here, the O-Cl polyatomic ion is covalently bonded, and would be linear, however a crystal lattice exists due to the ionic nature too

Salts (ionic bonds) exists geometrically in crystal lattices

<table>
<thead>
<tr>
<th>Compound</th>
<th>Points</th>
<th>Round #1</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-C(=O)-Br</td>
<td>Molecular +1</td>
<td></td>
</tr>
<tr>
<td>1 double bond +1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-C bond = non-polar C-O &amp; C-Br = polar +3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polar overall +1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry unknown +1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na+ [O-Cl]</td>
<td>Non-Molecular +1</td>
<td></td>
</tr>
<tr>
<td>1 ionic bond +1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O-Cl bond = polar +1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polar overall +1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry crystal lattice &amp; linear +1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[K⁺₂][S⁻²]</td>
<td>Non-Molecular +1</td>
<td></td>
</tr>
<tr>
<td>2 ionic bonds +2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry crystal lattice +1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- pts for unbonded elements 0
Total pts for Round 16 pts
Overall Total pts 16 pts
Worksheet #2: Quiz for Foolish Formulas

Name: Foolish Formulas
Period: 9 ¾

Directions: The following represents a quiz that I gave; this student got every question wrong. Figure out what the student did incorrectly and correct their paper with the right answers. Then discuss with a partner why the original answers were incorrect.

1.) Combine the following anions and cations in order to make neutral compounds:
   
   A) Fe$^{2+}$ and O$^{2-}$ __________ Fe$_2$O$_2$ __________________________
   B) Co$^{3+}$ and F$^{-}$ __________ Co$_3$F __________________________
   C) Ca$^{2+}$ and OH$^{-}$ __________ CaOH$_2$ __________________________
   D) Mn$^{3+}$ and CrO$_4^{2-}$ __________ Mn$_2$Cr$_3$O$_{12}$ ________________
   E) Ni$^{3+}$ and CN$^{-}$ __________ Ni(III)CN ____________________________

2.) Name each of the following neutral compounds:
   
   MnO ______ magnesium oxide __________________________________________
   FeCl$_2$ ______ iron (II) chloride (I) ____________________________________
   CrI$_3$ ______ chromium iodide __________________________________________
   MgCl$_2$ ______ magnesium (II) perchloride ______________________________
   LiH ______ lithium hydroxide __________________________________________
   CaCl$_2$ ______ calcium chlorine __________________________________________

3.) Write the formula for each of the following names:
   
   Rubidium iodide __________ Rb$^{+1}$I$^{-1}$ _____________________________
   Francium chloride __________ FCl ________________________________
   Calcium phosphide __________ Ca$_2$P$_3$ _____________________________
   Iron (II) oxide __________ Fe$_{II}$/O _________________________________
   Iron (III) oxide __________ Fe$_{III}$/O$_3$ _____________________________
   Potassium carbide __________ KC ______________________________________

4.) Name each of the following compounds containing polyatomic ions

   NH$_4$Cl ______ nitrogen hydrogen chloride ____________________________
   Na$_2$SO$_4$ ______ sodium sulfur oxide __________________________________
   Mg(ClO$_3$)$_2$ ______ magnesium (II) chlorate ___________________________
H$_3$OBr ________hydrogen hypobromite________________________
FeCrO$_4$ _______iron chlromate______________________________

5.) Write the formula for each of the following:

Manganese (IV) chlorite _______MnCl$_4$_____________________
Aluminum phosphate _______Al$_2$P$_3$_______________________
Cobalt (III) carbonate _______Co$_{III}$CO$_3$_________________
Silver sulfate ___________SiSO$_4$__________________________
### Module-specific Glossary #1: Etymology of IUPAC Nomenclature

#### Etymological Glossary for Module #5

<table>
<thead>
<tr>
<th>Word</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>acet</td>
<td>(Latin) Vinegar</td>
<td>Ex: Acetic acid, Acetate</td>
</tr>
<tr>
<td>ate</td>
<td>(Science) Salt from -ic acids</td>
<td>Ex: Sulfate</td>
</tr>
<tr>
<td>carbon</td>
<td>(Chemistry) Contains Carbon</td>
<td>Ex: Carbonic acid, Carbonate</td>
</tr>
<tr>
<td>chlor</td>
<td>(Chemistry) Contains Chlorine</td>
<td>Ex: Chlorine, Perchloric acid</td>
</tr>
<tr>
<td>chrom</td>
<td>(Chemistry) Contain Chromium</td>
<td>Ex: Chromium, Dichromate</td>
</tr>
<tr>
<td>cyan</td>
<td>(Chemistry) Contains a carbon atom triple bonded to a nitrogen atom</td>
<td>Ex: Cyanogen, Cyanide</td>
</tr>
<tr>
<td>di</td>
<td>(Latin) Two</td>
<td>Ex: Dichromate</td>
</tr>
<tr>
<td>gen</td>
<td>(Chemistry) Non-metal elements</td>
<td>Ex: Oxygen</td>
</tr>
<tr>
<td>hydro</td>
<td>(Latin) Contains water</td>
<td>Ex: Hydrate</td>
</tr>
<tr>
<td>hydro</td>
<td>(Chemistry) Contains Hydrogen</td>
<td>Ex: Hydronium</td>
</tr>
<tr>
<td>hypo</td>
<td>(Greek) Under, below</td>
<td>Ex: Hypochlorite</td>
</tr>
<tr>
<td>ic</td>
<td>(Latin) Pertaining to high valence acid</td>
<td>Ex: Hydrochloric</td>
</tr>
<tr>
<td>ide</td>
<td>(Science) Anion or ionic salt</td>
<td>Ex: Chloride, Sodium Chloride</td>
</tr>
<tr>
<td>ite</td>
<td>(Science) Salts from -ous acids</td>
<td>Ex: Hypochlorite</td>
</tr>
<tr>
<td>ium</td>
<td>(Science) Metallic Cation or Element</td>
<td>Ex: Sodium Chloride</td>
</tr>
<tr>
<td>mangan</td>
<td>(Chemistry) Contains Manganese</td>
<td>Ex: Manganese</td>
</tr>
<tr>
<td>nitr</td>
<td>(Chemistry) Contains Nitrogen</td>
<td>Ex: Nitrate</td>
</tr>
<tr>
<td>ous</td>
<td>(Science) Pertaining to low valence acid</td>
<td>Ex: Sulfurous acid</td>
</tr>
<tr>
<td>oxal</td>
<td>(Greek) Sour</td>
<td>Ex: Oxalic Acid</td>
</tr>
<tr>
<td>oxy</td>
<td>(Chemistry) Contains Oxygen</td>
<td>Ex: Peroxide</td>
</tr>
<tr>
<td>per</td>
<td>(Chemistry) Denotes maximum amount of element within a compound (often 4)</td>
<td>Ex: Permanganate</td>
</tr>
<tr>
<td>phosph</td>
<td>(Chemistry) Contains Phosphorus</td>
<td>Ex: Phosphate</td>
</tr>
<tr>
<td>sulf</td>
<td>(Chemistry) Contains Sulfur</td>
<td>Ex: Sulfurous acid</td>
</tr>
<tr>
<td>thio</td>
<td>(Chemistry) Contains Sulfur (or in rare cases, oxygen)</td>
<td>Ex: Thiosulfate</td>
</tr>
</tbody>
</table>

### Examples of Etymological Analysis

- **Hydronium**: Hydro + (n)ium
  - **Metallic Cation** of Hydrogen or water
  - Formula Explanation: Metals prefer to lose electrons to become cations. So if hydrogen or water is to act like a metal, it would become a cation. Thus Hydronium is $H^+$ or $H_2O^+$

- **Acetate**: Acet(ic acid) + ate
  - **Salt of** Vinegar acid ending in "ic"
  - Formula Explanation: Vinegar is the common name of acetic acid, which is $\text{CH}_3\text{COOH}$. Acetic acid becomes a salt, acetate, by losing a hydrogen. Thus Acetate is $\text{CH}_3\text{COO}^-$

- **Cyanide**: Cyan + ide
  - **Anion** of a Carbon triple bonded to Nitrogen
Formula: Cyanide is \( \text{CN}^- \)
Carbonate
Carbon (ic acid) + ate Salt of Carbon acid ending in "ic"
Formula Explanation: Carbonic Acid is \( \text{H}_2\text{CO}_3 \). Carbonic acid becomes a salt, carbonate, by losing two hydrogen atoms. Thus Carbonate is \( \text{CO}_3^{2-} \).

Hydrogen Carbonate
Hydrogen + Carbon (ic acid) + ate Salt of Carbon acid ending in "ic" with a Hydrogen
Formula Explanation: See Carbonate explanation. Carbonate is \( \text{CO}_3^{2-} \). Thus with the addition of a hydrogen, Hydrogen Carbonate is \( \text{HCO}_3^- \).

Oxalate
Oxal (ic acid) + ate Salt of Sour acid ending in "ic"
Formula Explanation: Oxalic Acid is \( \text{H}_2\text{C}_2\text{O}_4 \). Its name comes from the Greek word for sour, because acids often taste sour. Oxalic acid becomes a salt, oxalate, by losing two hydrogen atoms. Thus Oxalate is \( \text{C}_2\text{O}_4^{2-} \).

Hypochlorite
Hypo + chlor + ite Salt of an acid with low chlorine that ends in "ous"
Formula Explanation: Hypochlorite is the salt of Hypochlorous acid. Hypochlorous acid is \( \text{HClO} \). Hypochlorous acid becomes a salt, by losing a hydrogen. Thus Hypochlorite is \( \text{ClO}^- \).

Chlorite
Chlor + ite Salt of an acid with chlorine that ends in "ous"
Formula Explanation: Chlorite is the salt of Chlorous acid. Chlorous acid is \( \text{HClO}_2 \). Chlorous acid becomes a salt, by losing a hydrogen. Thus Chlorite is \( \text{ClO}_2^- \).

Chlorate
Chlor + ate Salt of an acid of chlorine that ends in "ic"
Formula Explanation: Chlorate is the salt of Chloric acid. Chloric acid is \( \text{HClO}_3 \). Chloric acid becomes a salt, by losing a hydrogen. Thus Chlorate is \( \text{ClO}_3^- \).

Perchlorate
Per + chlor + ate Salt of an acid of maximized chlorine that ends in "ic"
Formula Explanation: Perchlorate is the salt of Perchloric acid. Perchloric acid is \( \text{HClO}_4 \), which has chlorine attached to a maximum number of oxygen atoms. Perchloric acid becomes a salt, by losing a hydrogen. Thus Perchlorate is \( \text{ClO}_4^- \).

Chromate
Chrom + ate Salt of an acid of chromium that ends in "ic"
Formula Explanation: Chromate is the salt of Chromic acid. Chromic acid is \( \text{H}_2\text{CrO}_4 \). Chromic acid becomes a salt, by losing two hydrogen atoms. Thus Chromate is \( \text{CrO}_4^{2-} \).

Dichromate
Chrom + ate Salt of an acid of two chromium atoms that ends in "ic"
Formula Explanation: Dichromate is the salt of Dichromic acid. Dichromic acid is \( \text{H}_2\text{Cr}_2\text{O}_7 \). Dichromic acid becomes a salt, by losing two hydrogen atoms. Thus Dichromate is \( \text{Cr}_2\text{O}_7^{2-} \).

Permanganate
Per + mangan + ate Salt of an acid of maximized chromium that ends in "ic"
Formula Explanation: Permanganate is the salt of Permanganic acid. Permanganic acid is \( \text{HMnO}_4 \), which has manganese attached to a maximum number of oxygen atoms. Permanganic acid becomes a salt, by losing a hydrogen. Thus Permanganate is \( \text{MnO}_4^- \).

Nitrite
Nitr + ite Salt of an acid with nitrogen that ends in "ous"
Formula Explanation: Nitrite is the salt of Nitrous acid. Nitrous acid is \( \text{HNO}_2 \). Nitrous acid becomes a salt, by losing a hydrogen. Thus Nitrite is \( \text{NO}_2^- \).
Nitrates: Salt of an acid of nitrogen that ends in "ic"

Formula Explanation: Nitrate is the salt of Nitric acid. Nitric acid becomes a salt, by losing a hydrogen. Thus Nitrate is NO$_3^-$

Peroxides: Per + ox + ide Anion of maximized oxygen

Formula Explanation: Peroxide is the anion of maximized oxygen. Thus Peroxide is O$_2^{2-}$

Hydroxides: Hydr(o) + ox + ide Anion of Hydrogen and oxygen

Formula Explanation: Hydroxide is OH$^-$

Phosphates: Phosph(or) + ate Salt of an acid of phosphorus that ends in "ic"

Formula Explanation: Phosphate is the salt of Phosphoric acid. Phosphoric acid is H$_3$PO$_4$. Phosphoric acid becomes a salt, by losing three hydrogen atoms. Thus Phosphate is PO$_4^{3-}$

Thiocyanate: Thio + cyan + ate

Formula: Thiocyanate is SCN$^-$

Sulfites: Sulf(ur) + ite Salt of an acid of sulfur that ends in "ous"

Formula Explanation: Sulfite is the salt of Sulfurous acid. Sulfurous acid is H$_2$SO$_3$. Sulfurous acid becomes a salt, by losing two hydrogen atoms. Thus Sulfite is SO$_3^{2-}$

Sulfates: Sulf(ur) + ate Salt of an acid of sulfur that ends in "ic"

Formula Explanation: Sulfate is the salt of Sulfuric acid. Sulfuric acid is H$_2$SO$_4$. Sulfuric acid becomes a salt, by losing two hydrogen atoms. Thus Sulfate is SO$_4^{2-}$

Hydrogen Sulfate: Hydrogen + Sulf(uric acid) + ate

Formula Explanation: See Sulfate explanation. Sulfate is SO$_4^{2-}$. Thus with the addition of a hydrogen, Hydrogen Sulfate is HSO$_4$.

Thiosulfates: Thio + Sulf(uristic acid) + ate

Formula Explanation: See Sulfate Explanation. Sulfate is SO$_4^{2-}$. Because of the thio prefix, one of the oxygen atoms in sulfate is replaced with a sulfur atom. Thus Thiosulfate is S$_2$O$_3^{2-}$
Module-specific Glossary #2: Vocabulary of Compound Terms

Vocabulary Glossary for Module #5

**Binary Compound**  
A compound that contains only two elements. May be covalently or ionically bonded.  
**Note:** Refer to *Compound*

**Compound**  
A group of atoms or ions held together by chemical bonds. Sometimes used interchangeably with molecule, however molecules are specifically for covalently bonded compounds.  
**Note:** Refer to *Molecule*

**Formula**  
A kind of chemical notation that indicates the composition of a compound by listing the type and number of atoms within said compound.  
(Translation) A combination of atomic symbols that is used to describe and identify compounds

**IUPAC Nomenclature**  
The classification and notation system for chemicals as determined by the International Union of Pure and Applied Chemistry.  
(Translation) The set of rules for naming compounds

**Oxidation State**  
An integer that represents the actual or hypothetical charge of an atom within a compound.
Module-specific Glossary #3: Symbols of Molecular Formulas

Symbol Glossary for Module #5

Singular Symbols
(I) Roman numerals within IUPAC Nomenclature indicates the oxidation state of the element they follow, and can be as low as I to as high as VII

Types of Symbol Notation

Molecular Formula A kind of chemical notation that indicates the composition of a compound by listing the type of atoms with their elemental symbols and indicating the number of atoms.
(Looks like) CO$_2$$^-$$^2$
where the _________ is the...

Subscript The number of atoms of the preceding elemental symbol
(Looks like) CO$_2$$^-$$^2$

Superscript The overall charge of the compound or ion
(Looks like) CO$_2$$^2$
**Module Kit #6**

**College at Brockport, Department of Education & Human Development**

**Linguistic Strategies for Chemistry - Module #6**

Designed by Genevieve Criss

<table>
<thead>
<tr>
<th>Associated Chemistry Unit:</th>
<th>Unit #6: Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit Subject or Content area:</strong></td>
<td>Chemical Reactions; Synthesis, Decomposition, Replacements &amp; Combustion</td>
</tr>
<tr>
<td><strong>Module Title:</strong></td>
<td>Writing and Reading Chemical Sentences with proper Grammar: Stoichiometrically Balanced Chemical Equations</td>
</tr>
</tbody>
</table>

**Module Overview**

*Provide a narrative that explains what language needs this module supports and why it is relevant?*

The sixth unit of chemistry focuses on the last major segment of chemical language: reading and writing chemical equations, which are equivalent to chemical sentences. Using knowledge from Units #2, #4 & #5, molecular formulas are expressed together in chemical equations in a way which not only depicts the behavior but also the quantity of molecules. While chemical equations focus on only one of the major dialects of chemical language: formulas, equations can be written in the other dialects as well. Once students have mastered chemical reactions, all future chapters build off of this skill and will primarily only require review and extrapolated supports. For example, Acid-Base Reactions are a specific sub-type of chemical reactions and follow the same rules as writing chemical reactions.

The central learning objective here is for students to be able to decode and encode chemical equations. Students must be able to identify the reaction type from a given chemical equation, as well as balanced the equation stoichiometrically. Students should be able to write their own chemical equation when given information in another chemical 'dialect' or to translate between dialects. In later units, students will be expected to predict products or reactants when given incomplete chemical equations. All of these skills requires specific heuristic activities and other supports, ranging from pictoral to metacognitive strategies. Symbolic glossaries can proof to be incredibly useful here.

Empirical Formulas also appear in this unit, which require adjusted supports and review from Molecular Formulas in Unit #5.

Overall, this unit provides students with the foundational skill-set needed to be successful in chemistry: the ability to read and write chemical equations. Once students have mastered that skill, including in various dialects, they will be prepared for all future units, which provide specialized forms of chemical equations, such as Acid-Base or Redox Reactions.

**Module Objective(s):** *Develop an objective statement that aligns with the language needs and uses observable and measurable goals.*

The primary goal of this module is develop student ability to write, read and otherwise analyze Chemical Equations, which demonstrates a mastery over chemical reactions. This skills are crucial for students to succeed in chemistry. Specific objectives are:

- When provided with a molecular formula, students will be able to simplify it mathematically to the correct empirical formula with the use of a calculator as needed.
- When provided with an empirical formula and a molecular weight, students will be able to calculate the molecular formula accurately with the use of a calculator as needed.
- When provided with a chemical equation, students will be able to correctly identify the type of reaction it depicts.
- When provided with a chemical equation, students will be able to 'translate' the chemical equation into a dialect other than the formulaic form (structural or nomenclature).
• When provided with a description of a reaction in a dialect other than formulaic (structural or nomenclature), students will be able to accurately write the chemical equation.
• When provided with an unbalanced chemical equation, students will be able to accurately balance the equation stoichiometrically with the use of a calculator as needed.

**Content Outline**

1) Knowledge
   • Etymology  Reaction Morphemes
   • Symbols  Chemical Equation
   • Vocabulary  Empirical Formula, Reaction, Synthesis, Decomposition, Single & Double Replacement, Combustion, Chemical Equation, Stoichiometry

2) Skills
   • Ability to...  Identify Reaction types from Chemical Equations
   • Ability to...  Read and write (Decode & Encode) Chemical Equations
   • Ability to...  Stoichiometrically Balance Chemical Equations

3) Values
   • Demonstrate...  Recognition that Chemical Language spans across the multiple scalar realms of Chemistry and can describe Real Life Observations or Creations of Imagination

**Activities and Instructional Strategies**

1) Challenge:  Differentiation of Paired/Related Concepts
   Applicable to:  Empirical vs Molecular Formula, Reaction Types, Chemical Formula vs Equation

Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Types</td>
<td>Analysis of Reaction Morphemes</td>
<td>Using the etymological glossary as a reference, explicitly demonstrate the metacognitive process to analyze the morphemes within reaction types to ascertain their meaning. This process is also known as decoding. (See Glossary #1 in Supplemental Materials Appendix for Module #6; See Etymology Glossary in Supplemental Materials Appendix for all Modules)</td>
</tr>
<tr>
<td>Empirical vs Molecular Formula</td>
<td>Formula Forks</td>
<td>Provide students with a blank graphic organizer that depicts a hierarchical relationship between molecular and empirical formulas. Students can be given multiple molecular formulas that simplify to a few empirical formulas, which they need to calculate and then fill into the graphic organizers. Thus, the graphic organizer will demonstrate the relationship and key differences between molecular and empirical formulas. Additionally, the graphic organizer can also be expanded to demonstrate</td>
</tr>
</tbody>
</table>
2) Challenge: Differentiation of Scientific & Colloquial Meanings
Applicable to: Equation, Empirical, Reaction Types
Possible Activities

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Support Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Equation vs. Formula</td>
<td>The Secret Formula Continued</td>
<td>Formula and Equation have multiple definitions colloquially, some of which are very applicable and similar to the chemical meanings. The applicable colloquial definition should be highlighted and separated from less applicable colloquial definitions. While the mathematic definitions can cause problematic confusion, if presented in an explicit and clear manner, can be incredibly helpful. An equation is an expression with an equal sign, which is parallel to the chemical equation with an arrow. The mathematical formula is a set of instructions (which often causes confusion due to overlapping formulas and equations). However, the analogy of for example a soda formula can be used, by drawing parallels between the ingredients in a soda formula and the atoms in a chemical formula. For more information, see The Secret Formula in Module #5.</td>
</tr>
<tr>
<td>Empirical</td>
<td>Narrative of a Chemist</td>
<td>The definitions of empirical evidence and empirical formulas seem to be at odds, until one gains understanding for laboratory methods of chemical identification. Empirical evidence is based on observations and experiments, rather than theory. When a scientist used laboratory methods (experiments) to determine the identity of a chemical, calculations initially give the scientist only the empirical formula. The scientist can then combine that with other information, such as molecular weight to determine true chemical formula. This information should be given to students either through a spoken narrative, or perhaps a youtube video, before providing the graphic organizer (same one as Challenge #1). Students can be given word problems that reflect the process that scientists go through in order to determine molecular formulas from the initial evidence of empirical formulas.</td>
</tr>
<tr>
<td>Reaction Types (Synthesis, Decomposition)</td>
<td>Is that really Organic?</td>
<td>Students often equate synthesis with the colloquial idea of &quot;synthetic&quot; materials. In other words, they intuitively believe that synthesis only occurs in the laboratory under 'unnatural' conditions. This is often due to the culprit of &quot;organic food&quot; culture. This mentality can be unraveled</td>
</tr>
</tbody>
</table>
by providing examples of 'natural' synthesis that occurs in the body, for example, how the human metabolism combines amino acids together to form proteins. Conversely, decomposition often displays the same limited mentality in reverse. Decomposition is often equated to decay, such as rotting food and organic materials, and not mentally associated with laboratory-based reactions. Encourage students to share their own real life examples and to reflect on their pre-conceived notions of natural versus unnatural. Additionally, examples of 'natural and unnatural' reactions (in nature vs in a laboratory) can be written into a provided graphic organizer to help remediate any pre-existing misconceptions.

3) Challenge: Identifying Reaction Types
Applicable to: Any Chemical Equation
Possible Activities
- Pictoral Equations - Often chemistry teachers provide a formula list that describes each type of chemical reaction (synthesis : A + B → C, Decomposition C → B + A, etc), however, this can sometimes just be another example of intimidating alphabet soup for students. Instead, these same formulas can be depicted with unique puzzle pieces instead of letters (A, B, C), which still provides the same formulaic information, but in a visual way that is less cognitively taxing (due to alphabet soup). Alternatively, the alphabetic formulas can also be adjusted with color coding or simplified atomic depictions to improve clarity (See Image #1 in Supplemental Materials Appendix for Module #6: originally retrieved from http://upload.wikimedia.org/wikipedia/commons/d/dc/Chemical_reactions.svg).
- Extrapolation/Continuation from "Is that really Organic?" above - "Is that really Organic?" connected Real Life examples to the different reaction types. Additionally, the graphic organizer used there can be expanded to also include structural depictions and IUPAC names.
- The Elements go to Prom AKA Shall we Dance - In this activity, students can either be given a packets that depicts each element as a dance partner or be asked to represent the elements themselves kinesthetically. In the packet, a narrative will be provided following the behaviors (reactions) of each element as they come together, break up or switch partners on the dance floor. Alternatively or additionally, students can be asked to write their own narratives depicting reaction types. In the kinestetic version, students act out these narratives by representing the elements behavior in reactions. (See Worksheet #1 in Supplemental Materials Appendix for Module #6: original retrieved from http://pogil.org/uploads/media_items/classifying-types-of-chemical-reactions.original.pdf)
- Side Note Chemical Equations Key: In the student notes packets, place a glossary box in the margins that defines the new symbols. Using the Periodic table and symbol glossary as a reference, explicitly demonstrate the metacognitive process to analyze the individual symbols within the chemical equation in order to identify the reaction type. For example, the meaning behind the positions of molecular formulas or heat (∆) in regards to the arrow (in front = reactant, behind = product) should be explicitly explained. Specifically, each chemical symbol should be labeled, and if possible step-wise instructions that explain how the formula was compiled from information from the periodic table. In particular, this heuristic method should be used to
demonstrate basic rules that can be applied to more complicated chemical equations. Further, comparisons of different chemical equations with labeled symbols can be provided. Alternatively, an entire symbol glossary can be provided. (See Glossary #3 in Supplemental Materials Appendix for Module #6; See Symbol Glossary in Supplemental Materials Appendix for all Modules)

4) Challenge: Read and write (Decode & Encode) Chemical Equations
Applicable to: All Chemical Equations
Possible Activities
- An Easy "Cheat" for Reactions - On the students Regents Reference packet, Table I shows multiple chemical equations in regards to heats of reaction. While heats of reaction are not relevant yet, students can be shown how to mark or highlight Table I in ways that support their understanding of chemical equations. In particular, students can be asked to identify the reaction type of each equation in Table I. Students are encouraged to develop their own preferred marking systems, which should support student navigation and application of the Periodic Table or Table I. As needed, provide the students with extra support such as the student tips for Regents References packet.
- Extrapolation/Continuation from Challenge #3 above - "Side Note Chemical Equations Key" covered Decoding & Encoding reaction equations in respect to reaction type. However, said strategy used there can be reviewed and then expanded upon to demonstrate how to read and write chemical equations, for example, in order to determine a missing compound.

5) Challenge: Stoichiometrically Balance Chemical Equations
Applicable to: All Chemical Equations
- Extrapolation/Continuation from Challenge #3 & #4 Above - "Side Note Chemical Equations Key" covered Decoding & Encoding reaction equations in respect to reaction type or reading and writing reactions. However, said strategy used there can be reviewed and then expanded upon to demonstrate how to stoichiometrically balancing chemical equations.
- Extrapolation/Continuation from Pictoral Formulas (Challenge #3) - Aside from using pictoral formulas to demonstrate reaction types, pictoral formulas can also be used to help balance chemical equations. When provided with a graphic organizer and chemical equations needing balancing, students can draw the number of elements & molecules needed to balance the equation and then write the chemical equation in it's typical form. Alternatively, PhET simulations can also be used to the same effect (http://phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations-600.png). As can physical manipulatives, such as providing students with puzzle pieces or even jelly beans and a scale. Use of pictoral formulas can also be combined with other representations of chemical equations to promote the parallel presentation of chemistry dialects.

**Instructional Resources and Materials to engage students in learning:**

1) Module Specific: See Supplemental Materials Appendix for Module #5 Below
Images
- **Image #1:** Reaction Types for Pictoral Equations
Worksheets
- **Worksheet #1:** Activity for Shall We Dance
Module Specific Glossaries
2) General: See Supplemental Materials Appendix for all Modules Glossaries
   - **Glossary #1a**: Etymology Glossary for Scientific Terminology & Concepts
   - **Glossary #1b**: Etymological Glossary for IUPAC Nomenclature terminology
   - **Glossary #2**: Vocabulary Glossary for Scientific Concepts and Terminology
   - **Glossary #3**: Symbol Glossary for Mathematic and Chemical Symbols

Regents Reference Tables Supports
   - **Regents Reference Table Support #1**: Links for Navigating Regents Reference Tables
   - **Regents Reference Table Support #2**: Link to Interactive Online Periodic Table
   - **Regents Reference Table Support #3**: Etymological Analysis of Elemental Names
Relevant theories and/or research best practices:

What theories and scholarly sources ground your decisions about the learning tasks?

1) General Theories
   Linguistic Etymology, Specialized Glossaries, Mnemonic Devices, Visual supports, Metacognition, Code-switching & Translation

2) Research Articles

Etymology

Contradictory Definitions (Colloquial vs Scientific Language)

Metacognitive and other Linguistic Supports

Specialized Glossaries

Code-Switching
Appendix of Supplemental Materials for Module #6

**Image #1: Reaction Types for Pictoral Equations**

- **Synthesis**: \( \text{A} + \text{B} \rightarrow \text{A} \text{B} \)
- **Decomposition**: \( \text{A} \text{B} \rightarrow \text{A} + \text{B} \)
- **Single Replacement**: \( \text{A} \text{B} + \text{C} \rightarrow \text{A} \text{C} \text{B} \)
- **Double Replacement**: \( \text{A} \text{B} + \text{C} \text{D} \rightarrow \text{A} \text{C} + \text{B} \text{D} \)
Worksheet #1: Activity for Shall We Dance

Shall We Dance? – Classifying Types of Chemical Reactions

Why?

Chemical reactions can be classified into different categories. Four common types are synthesis, decomposition, single replacement and double replacement. Specific reactions corresponding to these general types are associated with health issues, environmental problems, and manufacturing processes. In order to use chemical reactions or evaluate their effects, you need to be able to identify the type of reaction.

Success Criteria

• Identify and differentiate between four types of chemical reactions: synthesis, decomposition, single replacement and double replacement.

Prerequisites

• Reaction equation nomenclature
• Balancing equations

New Concepts

Types of Chemical Reactions:

• Synthesis elements or less complex compounds come together to form a single more complex compound
• Decomposition a compound breaks apart into either elements or less complex compounds
• Single replacement a single element replaces another one in a compound
• Double replacement ions in a compound switch places with ions in another compound to form two new compounds

Model 1: Analogy - Dancing with Reactants

When you are thinking about the four different types of reactions I’d like you to think about its similarity to dancing (yes, dancing). I’ll show you what I mean.

The dance…

Adam and Barbara were both single. No one was talking about "Adam and Barbara" being together before the dance. They both go to the dance alone. However, they meet at just the perfect time when a song they both adore is playing. They end up holding hands the entire dance. After that fateful meeting no one ever sees Adam without Barbara, they are forever referred to as "Adam and Barbara".

Key Questions

1. Represent the drama of Adam and Barbara as a chemical equation? Use A to represent Adam and B to represent Barbara.

2. If A and B represent elements can you describe what is happening?
3. How would you classify A and B using the words from the New Concepts section on the first page of this activity?

The dance continues...

Later that same evening Xavier and Yasmine, who have been ‘the couple’ forever, have a heated quarrel and break up.

4. Represent the drama of Xavier and Yasmine as a chemical equation? Use \( X \) to represent Xavier and \( Y \) to represent Yasmine.

5. If \( X \) and \( Y \) represent elements can you describe what is happening?

6. How would you classify \( X \) and \( Y \) using the words from the New Concepts section on the first page of this activity?

7. What type of reaction is represented in the picture below? Write your own analogy for the reaction illustrated in the picture.
8. Write a chemical reaction for this scenario.

The dance continues...

In their blissful state, Adam and Barbara (AB) try to help Xavier and Yasmine (XY) reconcile their differences. After everyone agrees to stop quarreling, Adam asks Yasmine to dance. Xavier and Barbara decided that they will dance together as well.

9. Represent Adam and Barbara’s attempt to reconcile Xavier and Yasmine’s differences as a chemical equation.

10. How would you summarize this reaction?

11. What type of reaction does this scenario represent? (Based on the New Concepts words)

<table>
<thead>
<tr>
<th>Model 2: Types of</th>
<th>Example: Using Symbols</th>
<th>Example Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactions Classification (Type) of Reaction</td>
<td>A + B $\rightarrow$ AB</td>
<td>$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>----------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Synthesis</td>
<td>XY $\rightarrow$ X + Y</td>
<td>$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$</td>
</tr>
<tr>
<td>Decomposition</td>
<td>A + BC $\rightarrow$ AC + B</td>
<td>$2Al(s) + 3Cu(NO_3)<em>{2(aq)} \rightarrow 2Al(NO_3)</em>{3(aq)} + 3Cu(s)$</td>
</tr>
<tr>
<td>Single Replacement</td>
<td>AC + DE $\rightarrow$ AE + DC</td>
<td>$Pb(NO_3)<em>{3(aq)} + 2KI</em>{(aq)} \rightarrow PbI_{2(s)} + 2KNO_{3(aq)}$</td>
</tr>
</tbody>
</table>
Module-specific Glossary #1: Etymology of Reaction Morphemes

**Etymological Glossary for Module #6**

<table>
<thead>
<tr>
<th>Term</th>
<th>Origin</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>act</td>
<td>(Latin) To do</td>
<td></td>
<td>Ex: Reaction</td>
</tr>
<tr>
<td>bust</td>
<td>(Latin) To burn up</td>
<td></td>
<td>Ex: Combust</td>
</tr>
<tr>
<td>com</td>
<td>(Latin) With</td>
<td></td>
<td>Ex: Combust, Compose</td>
</tr>
<tr>
<td>compon</td>
<td>See compos</td>
<td></td>
<td></td>
</tr>
<tr>
<td>compos</td>
<td>(Latin) To put together</td>
<td></td>
<td>Ex: Decompose</td>
</tr>
<tr>
<td>de</td>
<td>(Latin) To remove or be opposite of</td>
<td></td>
<td>Ex: Decompose</td>
</tr>
<tr>
<td>equat</td>
<td>(Latin) To mark as equal</td>
<td></td>
<td>Ex: Equation</td>
</tr>
<tr>
<td>ion</td>
<td>(Latin) State or action of</td>
<td></td>
<td>Ex: Reaction</td>
</tr>
<tr>
<td>ment</td>
<td>(Latin) An act of</td>
<td></td>
<td>Ex: Replacement</td>
</tr>
<tr>
<td>metry</td>
<td>(Latin) A measure of</td>
<td></td>
<td>Ex: Stoichiometry</td>
</tr>
<tr>
<td>pos</td>
<td>(Latin) To put</td>
<td></td>
<td>Ex: Decompose</td>
</tr>
<tr>
<td>re</td>
<td>(Latin) Again or back</td>
<td></td>
<td>Ex: Reaction</td>
</tr>
<tr>
<td>stoichio</td>
<td>(Greek) Element</td>
<td></td>
<td>Ex: Stoichiometry</td>
</tr>
<tr>
<td>syn</td>
<td>(Greek) Together</td>
<td></td>
<td>Ex: Synthesis</td>
</tr>
<tr>
<td>thesis</td>
<td>(Greek) To place or propose</td>
<td></td>
<td>Ex: Synthesis</td>
</tr>
</tbody>
</table>

**Examples of Etymological Analysis**

- **Combustion**  
  com + bust + ion  
  The act of burning up (matter) with (other matter)

- **Decompose**  
  de + com + pos(e)  
  The opposite of to put together

- **Equation**  
  equat + ion  
  To be marked as equal

- **Reaction**  
  re + act + ion  
  To act again

- **Replacement**  
  re + act + ion  
  The act of placing (something) back

- **Stoichiometry**  
  stoichio + metry  
  A measure of elements

- **Synthesis**  
  re + act + ion  
  To place (something) together
Module-specific Glossary #2: Vocabulary of Reaction Terms

Vocabulary Glossary for Module #6

Combustion
A type of chemical reaction, in which carbon-based fuel and oxygen is
transformed into water vapor and carbon dioxide while releasing heat.

Note: Refer to Reaction

Decomposition
A type of chemical reaction, in which one compound is broken down into
two or more simpler compounds or elements.

Note: Refer to Reaction
Note: Compare to Synthesis

Double Replacement
A type of chemical reaction, in which two reactants trade two substituents
to form two new products.

Note: Refer to Reaction
Note: Compare to Single Replacement

Empirical Formula
A kind of chemical notation that indicates the basic composition of a
compound by listing the type and ratio of atoms within said compound.
This formula is determined by laboratory research methods and can be
used to calculate the molecular formula.
(Translation) A type of formula that indicates the basic ratio of atoms, but
not necessarily the exact number of atoms within a compound

Note: Compare to Formula

Equation
A type of notation that describes a chemical reaction, including the
molecular formulas of the reactants and products.
(Translation) A shorthand way to write a chemical reaction

Note: Refer to Reaction

Product
A compound that is produced as the result of a chemical reaction.

Note: Refer to Reaction
Note: Compare to Reactant

Reactant
A compound that is transformed by a chemical reaction into a product.

Note: Refer to Reaction
Note: Compare to Product

Reaction
The chemical phenomenon where a substance(s) undergoes a chemical
change by way of dissociation, recombination or rearrangement of atoms.
(Translation) A chemical change that produces a new substance.

Note: Refer to Chemical (change)

Single Replacement
A type of chemical reaction, in which two reactants trade one substituent
to form two new products.

Note: Refer to Reaction
Note: Compare to Double Replacement
**Stoichiometry**  A branch of chemistry that quantitatively counts the ratios of elements and compounds in chemical reaction. Ratios can refer to atoms or moles. (Translation) A numerical system for tracking atoms in a reaction to ensure that mass is conserved

**Synthesis**  A type of chemical reaction, in which two or more compounds are combined into one compound.

**Note:** Refer to Reaction

**Note:** Compare to Decomposition
Module-specific Glossary #3: Symbols of Reaction Equations

Symbol Glossary for Module #6

Types of Symbol Notation

Chemical Equation A kind of chemical notation that describes the process of a chemical reaction by listing involved chemicals by molecular formula, with the reactants placed before the arrow and the products after the arrow. (Looks like) \( 2\text{CH}_2 + 3\text{O}_2 \rightarrow 2\text{H}_2\text{O} + 3\text{CO}_2 + \Delta \)

where the _______ is the...

Numerical Script The number of molecules for the following molecular formula (Looks like) \( 2\text{CH}_2+ 3\text{O}_2 \rightarrow 2\text{H}_2\text{O} + 3\text{CO}_2 + \Delta \)

+ Indicates the chemical combination of the formulas around it

→ Indicates that a chemical change occurs

Δ Indicates the absorption of heat if placed before the arrow and the release of heat if placed after the arrow
### General Etymological Glossary for all Modules

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>able</td>
<td>See uble</td>
<td>Ex: Accurate</td>
</tr>
<tr>
<td>accur</td>
<td>(Latin) To do with care</td>
<td>Ex: Reaction</td>
</tr>
<tr>
<td>ace</td>
<td>See acc</td>
<td></td>
</tr>
<tr>
<td>acr</td>
<td>See acc</td>
<td></td>
</tr>
<tr>
<td>act</td>
<td>(Latin) To do</td>
<td>Ex: Trigonal</td>
</tr>
<tr>
<td>acu</td>
<td>See acc</td>
<td>Ex: Arian</td>
</tr>
<tr>
<td>al</td>
<td>See ial</td>
<td>Ex: Aquous</td>
</tr>
<tr>
<td>an</td>
<td>(Greek) Up</td>
<td>Ex: Polar</td>
</tr>
<tr>
<td>aqua</td>
<td>(Latin) Water</td>
<td></td>
</tr>
<tr>
<td>ar</td>
<td>(Latin) Pertaining to</td>
<td></td>
</tr>
<tr>
<td>at</td>
<td>See ate</td>
<td></td>
</tr>
<tr>
<td>ate</td>
<td>(Latin) To act by [verb] or to be like [adjective]</td>
<td>Ex: Configuration, Observation, Coordinate</td>
</tr>
<tr>
<td>atom</td>
<td>(Greek) Indivisible</td>
<td>Ex: Atomic</td>
</tr>
<tr>
<td>auf</td>
<td>(German) Up</td>
<td>Ex: Aufbau Theory</td>
</tr>
<tr>
<td>bau</td>
<td>(German) Build</td>
<td>Ex: Aufbau Theory</td>
</tr>
<tr>
<td>bol</td>
<td>(Greek) Cast (AKA model)</td>
<td>Ex: Symbol</td>
</tr>
<tr>
<td>bust</td>
<td>(Latin) To burn up</td>
<td>Ex: Combust</td>
</tr>
<tr>
<td>cat</td>
<td>(Greek) Down</td>
<td>Ex: Cation</td>
</tr>
<tr>
<td>centi</td>
<td>(Latin) Hundred</td>
<td>Ex: Centimeter, Centigrad</td>
</tr>
<tr>
<td>chem</td>
<td>(Latin) Transformation of matter</td>
<td>Ex: Chemistry, Chemical</td>
</tr>
<tr>
<td>cis</td>
<td>(Latin) cut</td>
<td>Ex: Precise</td>
</tr>
<tr>
<td>cis</td>
<td>(Latin) on the same side</td>
<td>Ex: Cis-isomer</td>
</tr>
<tr>
<td>co</td>
<td>See con</td>
<td></td>
</tr>
<tr>
<td>com</td>
<td>(Latin) With</td>
<td>Ex: Combust, Compose</td>
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<tr>
<td>compos</td>
<td>(Latin) To put together</td>
<td>Ex: Decompose</td>
</tr>
<tr>
<td>con</td>
<td>(Latin) Together or to the same degree</td>
<td>Ex: Covalent, Continuous, Configuration</td>
</tr>
<tr>
<td>de</td>
<td>(Latin) To remove or be opposite of</td>
<td>Ex: Decompose</td>
</tr>
<tr>
<td>deci</td>
<td>(Latin) Ten</td>
<td>Ex: Decimal, Decimeter</td>
</tr>
<tr>
<td>decim</td>
<td>See deci</td>
<td></td>
</tr>
<tr>
<td>dict</td>
<td>(Latin) To say</td>
<td>Ex: Predict</td>
</tr>
<tr>
<td>dis</td>
<td>(Latin) Apart</td>
<td>Ex: Dispersion</td>
</tr>
<tr>
<td>duct</td>
<td>(Latin) To lead</td>
<td>Ex: Conduction</td>
</tr>
<tr>
<td>Electr</td>
<td>(Old English) Electric</td>
<td>Ex: Electron</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Element</td>
<td>(Latin) Basic principle, rule</td>
<td>Ex: Elemental</td>
</tr>
<tr>
<td>Ence</td>
<td>(Latin) Having the quality or action of</td>
<td>Ex: Science, Valence</td>
</tr>
<tr>
<td>Endo</td>
<td>(Latin) In or to enter</td>
<td>Ex: Endothermic</td>
</tr>
<tr>
<td>Ent</td>
<td>(Latin) To be</td>
<td>Ex: Scientific, Kinetic, Covalent</td>
</tr>
<tr>
<td>Equat</td>
<td>(Latin) To mark as equal</td>
<td>Ex: Equation</td>
</tr>
<tr>
<td>Ery</td>
<td>See ry</td>
<td></td>
</tr>
<tr>
<td>Et</td>
<td>See ent</td>
<td></td>
</tr>
<tr>
<td>Exo</td>
<td>(Latin) Out or to exit</td>
<td>Ex: Exothermic</td>
</tr>
<tr>
<td>Figur</td>
<td>(Latin) Shape</td>
<td>Ex: Configuration</td>
</tr>
<tr>
<td>Gon</td>
<td>(Greek) Angle</td>
<td>Ex: Trigonal</td>
</tr>
<tr>
<td>Hedron</td>
<td>(Greek) Face or Plane</td>
<td>Ex: Tetrahedron</td>
</tr>
<tr>
<td>Hydro</td>
<td>(Latin) water</td>
<td>Ex: Hydrate</td>
</tr>
<tr>
<td>Ial</td>
<td>(Latin) Related to</td>
<td>Ex: Potential, Orbital</td>
</tr>
<tr>
<td>Ible</td>
<td>See ible</td>
<td></td>
</tr>
<tr>
<td>Ic</td>
<td>(Latin) Pertaining to</td>
<td>Ex: Chemical, Symbolic,Ionic, Polyatomic</td>
</tr>
<tr>
<td>Ics</td>
<td>See ic</td>
<td></td>
</tr>
<tr>
<td>If</td>
<td>(Latin) Has characteristics of</td>
<td>Ex: Scientific</td>
</tr>
<tr>
<td>Inter</td>
<td>(Latin) Between</td>
<td>Ex: Intermolecular</td>
</tr>
<tr>
<td>Intral</td>
<td>(Latin) Within</td>
<td>Ex: Intramolecular</td>
</tr>
<tr>
<td>Ion</td>
<td>(Greek) To go</td>
<td>Ex: Ionic</td>
</tr>
<tr>
<td>Ion</td>
<td>(Latin) State or action of</td>
<td>Ex: Observation, Configuration, Conduction, Reaction</td>
</tr>
<tr>
<td>Iso</td>
<td>(Old English) Equal</td>
<td>Ex: Isotope</td>
</tr>
<tr>
<td>Ist</td>
<td>(Latin) One who does</td>
<td>Ex: Chemist</td>
</tr>
<tr>
<td>Ity</td>
<td>(Latin) Having the quality or condition of</td>
<td>Ex: Conductivity, Solubility</td>
</tr>
<tr>
<td>Iive</td>
<td>(Latin) Tends to or has the nature of</td>
<td>Ex: Conductive, Electronegative</td>
</tr>
<tr>
<td>Kilo</td>
<td>(Greek) Thousand</td>
<td>Ex: Kilometer, Kilogram</td>
</tr>
<tr>
<td>Kin</td>
<td>(Greek) Movement</td>
<td>Ex: Kinetic</td>
</tr>
<tr>
<td>Ly</td>
<td>(Old German) Having the characteristics of</td>
<td>Ex: Accurately</td>
</tr>
<tr>
<td>Ly</td>
<td>(Old German) at the interval of</td>
<td></td>
</tr>
<tr>
<td>Macro</td>
<td>(Greek) Long</td>
<td>Ex: Macroscale</td>
</tr>
<tr>
<td>Mangan</td>
<td>(Chemistry) Manganese</td>
<td>Ex: Manganate</td>
</tr>
<tr>
<td>Ment</td>
<td>(Latin) An act of</td>
<td>Ex: Replacement</td>
</tr>
<tr>
<td>Metry</td>
<td>(Latin) A measure of</td>
<td>Ex: Stoichiometry, Symmetry</td>
</tr>
<tr>
<td>Micro</td>
<td>(Greek) small</td>
<td>Ex: Micrometer, Microscope, Submicroscale</td>
</tr>
<tr>
<td>Milli</td>
<td>(Latin) One thousandth</td>
<td>Ex: Millimeter</td>
</tr>
<tr>
<td>Nano</td>
<td>(Greek) Dwarf</td>
<td>Ex: Nanometer</td>
</tr>
<tr>
<td>Negat</td>
<td>(Latin) To deny</td>
<td>Ex: Electronegative</td>
</tr>
<tr>
<td>Neutr</td>
<td>(Old English) Neutral</td>
<td>Ex: Neutron</td>
</tr>
<tr>
<td>Word</td>
<td>Meaning</td>
<td>Example</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>non</td>
<td>(Latin) Not</td>
<td>Non-polar</td>
</tr>
<tr>
<td>not</td>
<td>(Latin) To know or to note</td>
<td>Notation</td>
</tr>
<tr>
<td>nucleus</td>
<td>(Latin) Kernel or inner part</td>
<td>Nucleus</td>
</tr>
<tr>
<td>observ</td>
<td>(Latin) To watch or heed</td>
<td>Observation</td>
</tr>
<tr>
<td>orbit</td>
<td>(Latin) Course or track</td>
<td>Orbital</td>
</tr>
<tr>
<td>ordin</td>
<td>(Latin) Order</td>
<td>Coordinate</td>
</tr>
<tr>
<td>ous</td>
<td>(Old English) Having the nature of</td>
<td>Continuous, Aqueous</td>
</tr>
<tr>
<td>particle</td>
<td>(Latin) Little part</td>
<td>Particle</td>
</tr>
<tr>
<td>per</td>
<td>(Latin) Thoroughly or through the means of</td>
<td>Dispersion</td>
</tr>
<tr>
<td>phys</td>
<td>(Greek) Nature or life</td>
<td>Physical</td>
</tr>
<tr>
<td>pico</td>
<td>(Spanish) Little bit</td>
<td>Picometer</td>
</tr>
<tr>
<td>pol</td>
<td>(Latin) Pole or the end of an axis</td>
<td>Polar</td>
</tr>
<tr>
<td>poly</td>
<td>(Greek) Many</td>
<td>Polyatomic ion</td>
</tr>
<tr>
<td>pon</td>
<td>(Latin) To put</td>
<td>Exponent</td>
</tr>
<tr>
<td>pos</td>
<td>(Latin) To put</td>
<td>Decompose</td>
</tr>
<tr>
<td>posit</td>
<td>(Latin) To place</td>
<td>Electropositive</td>
</tr>
<tr>
<td>potent</td>
<td>(Latin) Ability or power</td>
<td>Potential</td>
</tr>
<tr>
<td>pre</td>
<td>(Latin) Before</td>
<td>Precise, Predict</td>
</tr>
<tr>
<td>precipi</td>
<td>(Latin) Hurl down</td>
<td>Precipitate</td>
</tr>
<tr>
<td>prot</td>
<td>(Greek) First or most important</td>
<td>Proton</td>
</tr>
<tr>
<td>pyramid</td>
<td>(Latin) Pyramid-shape</td>
<td>Pyramidal</td>
</tr>
<tr>
<td>re</td>
<td>(Latin) Again or back</td>
<td>Reaction</td>
</tr>
<tr>
<td>ry</td>
<td>(Old French) Craft, group or place of [noun]</td>
<td>Chemistry</td>
</tr>
<tr>
<td>ry</td>
<td>(Old French) Has characteristic of [adjectives]</td>
<td></td>
</tr>
<tr>
<td>sci</td>
<td>(Latin) To know or knowledge</td>
<td>Science, Scientific</td>
</tr>
<tr>
<td>scope</td>
<td>(Greek) To view or aim</td>
<td>Spectroscope, Microscope</td>
</tr>
<tr>
<td>sol</td>
<td>(Latin) To loosen</td>
<td>Soluble</td>
</tr>
<tr>
<td>solu</td>
<td>See sol</td>
<td></td>
</tr>
<tr>
<td>solv</td>
<td>See sol</td>
<td></td>
</tr>
<tr>
<td>spectr</td>
<td>(Latin) Image</td>
<td>Spectrum, Spectroscope</td>
</tr>
<tr>
<td>stoichio</td>
<td>(Greek) Element</td>
<td>Stoichiometry</td>
</tr>
<tr>
<td>sub</td>
<td>(Latin) Below or under</td>
<td>Submicroscopic</td>
</tr>
<tr>
<td>sym</td>
<td>(Latin) Same</td>
<td>Symmetry, Symbol</td>
</tr>
<tr>
<td>syn</td>
<td>(Greek) Together</td>
<td>Synthesis</td>
</tr>
<tr>
<td>ten</td>
<td>(Latin) To hold</td>
<td>Continuous</td>
</tr>
<tr>
<td>tetra</td>
<td>(Latin) Four</td>
<td>Tetrahedron</td>
</tr>
<tr>
<td>therm</td>
<td>(Greek) Heat</td>
<td>Exothermic, Endothermic</td>
</tr>
<tr>
<td>thesis</td>
<td>(Greek) To place or propose</td>
<td>Synthesis</td>
</tr>
<tr>
<td>tin</td>
<td>See ten</td>
<td></td>
</tr>
<tr>
<td>tope</td>
<td>(Greek) Place</td>
<td>Isotope</td>
</tr>
</tbody>
</table>
Glossary #1b: Etymological Glossary for IUPAC Nomenclature

**Nomenclature Etymological Glossary for all Modules**

<table>
<thead>
<tr>
<th>Greek &amp; Latin Numerical Prefixes</th>
<th>Organic Numerical Prefixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>That indicate number of substituents</td>
<td>Indicates number of carbons in a 'chain'</td>
</tr>
<tr>
<td>Mono</td>
<td>Meth</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Di</td>
<td>Eth</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Tri</td>
<td>Tri</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Tetra</td>
<td>Tetra</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Pent</td>
<td>Pent</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Hex</td>
<td>Hex</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Hept</td>
<td>Hept</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Oct</td>
<td>Oct</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Non</td>
<td>Non</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Dec</td>
<td>Dec</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

- **tri** (Latin) Three | Ex: **Trigonal**
- **uble** (Latin) Able to | Ex: **Soluble**
- **valen** (Latin) Power | Ex: **Valence**

- **acet** (Latin) Vinegar | Ex: **Acetic** acid, **Acetate**
- **al** From aldehyde, a compound that has at least one carbon double bonded to an oxygen and single bonded to a hydrogen | Ex: **propanal**
- **alk** From alkyl, a hydrocarbon | Ex: **alkane**, **alkene**, **alkyne**,
- **amide** From amide, a compound that has at least one carbon double bonded to an oxygen and single bonded to an amine | Ex: **propanamide**
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>amine</td>
<td>From amine, a compound that has at least one nitrogen atom single bonded to three substituents</td>
<td>propanamine</td>
</tr>
<tr>
<td>ane</td>
<td>A saturated hydrocarbon</td>
<td>alkane, haloalkane</td>
</tr>
<tr>
<td>ate</td>
<td>(Science) Salt from -ic acids</td>
<td>Sulfate</td>
</tr>
<tr>
<td>carbon</td>
<td>(Chemistry) Contains Carbon</td>
<td>Carbonic acid, Carbonate</td>
</tr>
<tr>
<td>chlor</td>
<td>(Chemistry) Contains Chlorine</td>
<td>Chlorine, Perchloric acid</td>
</tr>
<tr>
<td>chrom</td>
<td>(Chemistry) Contains Chromium</td>
<td>Chromium, Dichromate</td>
</tr>
<tr>
<td>cyan</td>
<td>(Chemistry) Contains a carbon atom triple bonded to a nitrogen atom</td>
<td>Cyanogen, Cyanide</td>
</tr>
<tr>
<td>di</td>
<td>(Latin) Two</td>
<td>Dichromate</td>
</tr>
<tr>
<td>ene</td>
<td>An unsaturated hydrocarbon that has at least one double bond</td>
<td>Alkene</td>
</tr>
<tr>
<td>ether</td>
<td>From ether, a compound that has at least one oxygen bonded to no hydrogens</td>
<td>Diethyl Ether</td>
</tr>
<tr>
<td>gen</td>
<td>(Chemistry) Non-metal elements</td>
<td>Oxygen</td>
</tr>
<tr>
<td>hydro</td>
<td>(Latin) Contains water</td>
<td>Hydrate</td>
</tr>
<tr>
<td>hydro</td>
<td>(Chemistry) Contains Hydrogen</td>
<td>Hydronium</td>
</tr>
<tr>
<td>hyp</td>
<td>(Greek) Under, below</td>
<td>Hypochlorite</td>
</tr>
<tr>
<td>ic</td>
<td>(Latin) Pertaining to high valence acid</td>
<td>Hydrochloric</td>
</tr>
<tr>
<td>ide</td>
<td>(Science) Anion or ionic salt</td>
<td>Chloride, Sodium Chloride</td>
</tr>
<tr>
<td>ine</td>
<td>(Science) Halogen Elements</td>
<td>Chlorine, Bromine</td>
</tr>
<tr>
<td>ite</td>
<td>(Science) Salts from -ous acids</td>
<td>Hypochlorite</td>
</tr>
<tr>
<td>ium</td>
<td>(Science) Metallic Cation or Element</td>
<td>Sodium Chloride</td>
</tr>
<tr>
<td>mangan</td>
<td>(Chemistry) Contains Manganese</td>
<td>Manganate</td>
</tr>
<tr>
<td>nitr</td>
<td>(Chemistry) Contains Nitrogen</td>
<td>Nitrate</td>
</tr>
<tr>
<td>oic acid</td>
<td>From carboxylic acid, a compound that has at least carbon double bonded to an oxygen and single bonded to an alcohol</td>
<td>Propanoic acid</td>
</tr>
<tr>
<td>ol</td>
<td>From alcohol, a compound that has at least one oxygen bonded to a hydrogen</td>
<td>Propanol</td>
</tr>
<tr>
<td>on</td>
<td>(Science) Non-metal Element</td>
<td>Carbon, Boron</td>
</tr>
<tr>
<td>one</td>
<td>From ketone, a compound that has at least one carbon double bonded to an oxygen and bonded to no hydrogen</td>
<td>Propanone</td>
</tr>
<tr>
<td>ous</td>
<td>(Science) Pertaining to low valence acid</td>
<td>Sulfurous acid</td>
</tr>
<tr>
<td>oxal</td>
<td>(Greek) Sour</td>
<td>Oxalic Acid</td>
</tr>
<tr>
<td>oxy</td>
<td>(Chemistry) Contains Oxygen</td>
<td>Peroxide</td>
</tr>
<tr>
<td>per</td>
<td>(Chemistry) Denotes maximum amount of element within a compound (often 4)</td>
<td>Permanganate</td>
</tr>
<tr>
<td>phosph</td>
<td>(Chemistry) Contains Phosphorus</td>
<td>Phosphate</td>
</tr>
<tr>
<td>sulf</td>
<td>(Chemistry) Contains Sulfur</td>
<td>Sulfurous acid</td>
</tr>
<tr>
<td>thio</td>
<td>(Chemistry) Contains Sulfur (or in rare cases, oxygen)</td>
<td>Thiosulfate</td>
</tr>
<tr>
<td>yne</td>
<td>An unsaturated hydrocarbon that has at least one triple bond</td>
<td>Alkyne</td>
</tr>
</tbody>
</table>
Glossary #2: Vocabulary Glossary for Scientific Concepts and Terminology

Vocabulary Glossary for all Modules

NOTE: Some definitions were retrieved from:
  http://antoine.frostburg.edu/chem/senese/101/glossary/a.shtml
  http://www.chemistry-dictionary.com/definition/chemistry.php

Accuracy
The correctness of a measurement based on its comparison to the true
or accepted value
(Translation) How close a measurement is to the true value.
Note: Compare to Precision

Anion
A negatively charged ion
(Translation) An atom that has more electrons than protons
Note: Refer to Charge and Ion

Aqueous
A solution in which water is the solvent
(Translation) A mixture in which a substance is dissolved in water
Note: Compare to Solubility

Atom
The smallest particle of an element that retains the chemical properties of
the element.
(Translation) A basic unit of matter that has a nucleus, made of protons
and neutrons, and an electron cloud.
Note: Compare to Element and Subatomic Particles

Atomic Mass
The average mass of an atom of an element, which is the weighted average
of the masses of every isotope found in a typical sample of the element.
(Translation) The weighted average of the mass numbers of all naturally
occurring isotopes of an atom; given on the periodic table.
Note: Refer to Element and Isotope

Atomic Model
A structural depiction of an atom of an element on the subatomic scale,
which often shows the subatomic particles.
Note: Refer to Atom

Atomic Number
The number of protons in the nucleus of an atom, which determines an
element's structure, properties and location of the periodic table.
(Translation) The number of protons in an atom that defines the element.
Note: Refer to Protons

Aufbau Principle
A rule for writing ground state electron configurations, in which
electrons are filled from lowest Energy levels to highest.
(Translation) Literally, the electron "build-up" rule.
Note: Refer to Electron configurations, Ground state and Energy Level
Bent
A molecular shape, in which the central atom has two substituents that are approximately 105° apart and one or two lone pairs of electrons.

Note: Compare to Hund's Rule

Note: Refer to Molecular Geometry

Note: Compare to Linear, Tetrahedral and Trigonal Pyramidal

Binary Compound
A compound that contains only two elements. May be covalently or ionically bonded.

Note: Refer to Compound

Bond/Bonding
The attraction between atoms that holds molecules together, which results from electron interactions, such as sharing or transferring.

(Translation) When two atoms share or trade electrons, which causes the atoms to stick together

Bond Strength
A measure of how difficult it is to break a chemical bond, which is directly related to how much energy is required to break the bond.

(Translation) A strong bond is very stable, exists in a low energy state, and thus requires a lot of energy to break. A weak bond is not stable, exists in a higher energy state and thus does not require much energy to break.

Note: Refer to Bond

Cation
A positively charged ion

(Translation) An atom that has more protons than electrons

Note: Refer to Charge and Ion

Charge
A property of matter that is responsible for electrical phenomenon

Chemical
Relating to chemistry

Note: Refer to Chemistry

Chemical (substance)
A form of matter that has a fixed composition and properties.

(Translation) Substances such as elements, compounds and molecules.

Chemical (change)
A reaction of a chemical substance or substances that results in the dissociation, recombination or rearrangement of atoms.

(Translation) A change that produces a new substance

Note: Compare to Physical (change)

Note: Refer to Reaction

Chemistry
The branch of science that investigates the structure, properties, interactions and transformations of matter.

(Translation) The study of matter and how it changes.

Combustion
A type of chemical reaction, in which carbon-based fuel and oxygen is transformed into water vapor and carbon dioxide while releasing heat.

Note: Refer to Reaction
**Compound**
A group of atoms or ions held together by chemical bonds. Sometimes used interchangeably with molecule, however molecules are specifically for covalently bonded compounds.
*Note:* Refer to *Molecule*

**Conductivity**
A property of a substance that is able to transfer electricity through itself

**Coordinate**
A type of covalent bond, in which the two shared electrons originated from only one atom in the bond.
(Translation) A bond made when one atom contributes two electrons to be shared between itself and another atom
*Note:* Refer to *Bond*
*Note:* Compare to *Covalent Bond*

**Covalent**
A type of bond, in which two atoms share their electrons
*Note:* Refer to *Bond*
*Note:* Compare to *Ionic Bond*

**Decomposition**
A type of chemical reaction, in which one compound is broken down into two or more simpler compounds or elements.
*Note:* Refer to *Reaction*
*Note:* Compare to *Synthesis*

**Dipole**
A molecule that has both a partial positive and partial negative charge, usually due to electronegative atoms affecting the distribution of electrons
*Note:* Refer to *Electronegativity*

**Dispersion Forces**
The weakest type of intermolecular force, in which the attraction arises from temporary induced dipoles. Also known as London Forces
(Translation) A force of intermolecular attraction that occurs by chance when random electron movement creates one momentary dipole, which causes a chain effect of temporary dipoles among neighboring molecules
*Note:* Refer to *Intermolecular Forces* and *Dipoles*
*Note:* Compare to *Van Der Waals Forces*

**Double Bond**
A type of covalent bond, in which two atoms share four electrons
*Note:* Refer to *Covalent Bond*
*Note:* Compare to *Single Bond* and *Triple Bond*

**Double Replacement**
A type of chemical reaction, in which two reactants trade two substituents to form two new products.
*Note:* Refer to *Reaction*
*Note:* Compare to *Single Replacement*

**Electron**
A negatively charged subatomic particle found outside the nucleus of an atom that has a mass of approximately 1/1000 amu

**Electron Cloud**
The area outside the nucleus of an atom where electrons reside

**Electron Configuration**
A notation system that describes how many electrons are in each orbital for a specific atom.
**Electron Orbital**
A division of an energy level that contains two electrons with paired spins and is associated with a specific region of the electron cloud.

**Note:** Refer to *Electron orbital*

**Electronegativity**
A property of an atom based on its ability to attract electrons, which determines what type of bonds the atom can form. Sometimes used interchangeably with the term electron affinity.

(Translation) A measure of an atom's ability to attract electrons to itself.

**Note:** Compare to *Electropositivity*

**Electropositivity**
A property of an atom based on its ability to donate electrons, which determines what types of bonds the atom can form. The inverse property of electronegativity.

(Translation) The opposite of electronegativity. A measure of an atom's ability to give away its electrons.

**Note:** Compare to *Electropositivity*

**Element**
A substance that is only composed of the same atoms, all which have the same atomic number.

**Note:** Compare to *Atom*

**Empirical Formula**
A kind of chemical notation that indicates the basic composition of a compound by listing the type and ratio of atoms within said compound. This formula is determined by laboratory research methods and can be used to calculate the molecular formula.

(Translation) A type of formula that indicates the basic ratio of atoms, but not necessarily the exact number of atoms within a compound.

**Note:** Compare to *Formula*

**Endothermic**
A process that absorbs heat energy.

**Note:** Compare to *Exothermic*

**Energy**
A property of objects, which can be transferred to other objects or converted into other forms.

(Translation) Forms of power, such as light, heat and electricity, which often have the capacity to do work.

**Energy Level**
The possible locations in the electron cloud, where electrons that have a specific energy value, can be found.

**Note:** Compare to *Electron Orbital*

**Equation**
A type of notation that describes a chemical reaction, including the molecular formulas of the reactants and products.

(Translation) A shorthand way to write a chemical reaction.

**Note:** Refer to *Reaction*
Excited State
A state in which an atom has temporarily absorbed excess energy, which can result in an electron jumping up to a higher energy orbital or level. (Translation) A state with higher energy than the ground state of an atom, which can be shown with electron configurations that break Hund's rule.

Note: Refer to Energy Level, Electron Orbital, and Hund's Rule

Note: Compare to Ground State

Exothermic
A process that releases heat energy

Note: Compare to Endothermic

Formula
A kind of chemical notation that indicates the composition of a compound by listing the type and number of atoms within said compound. (Translation) A combination of atomic symbols that is used to describe and identify compounds

Ground State
The lowest energy and thus the most stable state for an atom or molecule, in which electrons reside in the lowest energy levels possible. (Translation) A state with the lowest energy of an atom, which can be shown with electron configurations that follow Hund's rule.

Note: Compare to Excited State

Note: Refer to Energy Level, Electron Configuration, and Hund's Rule

Heat
A form of energy that is proportional to the amount of molecular motion (Translation) A form of energy that is measured by temperature

Note: Refer to Temperature

Hund's Rule
A rule for writing ground state electron configurations, in which electrons are placed within the orbitals of an energy sublevel, so that the number of unpaired spins is maximized. In other words, electrons should only be paired with another electron within an orbital, after every other orbital within that energy sublevel has one electron occupant.

Note: Refer to Electron configurations, Orbital and Energy Sublevel

Note: Compare to Aufbau Principle

Hydrogen Bonding
A very strong intermolecular force, which is a dipole-dipole interaction between molecules that have a hydrogen attached to a highly electronegative atom, such as oxygen or nitrogen.

Note: Refer to Intermolecular Force, Electronegativity and Dipole

Intermolecular Forces
An attraction or repulsion between molecules, which are much weaker than bonds, such as hydrogen bonds, dispersion and Van der waals forces.

Note: Refer to Hydrogen Bond, Dispersion Forces and Van der Waals Forces

Note: Compare to Intramolecular Forces

Intramolecular Forces
An attraction within molecules that holds the atoms of that molecule together.
(Translation) A chemical bond.
Note: Refer to Bond
Note: Compare to Intermolecular Forces

Ion
An atom or molecule that has acquired a charge by either gaining or losing electrons.

Ionic
A type of bond, in which electrons are transferred from one atom to another, which results in opposite charges that attract
Note: Refer to Bond
Note: Compare to Covalent

Isotope
An atom of an element that has the same atomic number, but a different mass number.
(Translation) An atom of an element that has the same number of protons, but a different number of neutrons in their nucleus.
Note: Compare to Atom and Ion

IUPAC
The classification and notation system for chemicals as determined by the International Union of Pure and Applied Chemistry.
(Translation) The set of rules for naming compounds

Kinetic
Related to the rate of reaction

Kinetic (energy)
The energy that an object possesses, because of its motion
Note: Compare to Potential (energy)

Linear
A molecular shape, in which the central atom has two substituents that are 180° apart and no lone pairs of electrons.
Note: Refer to Molecular Geometry
Note: Compare to Bent, Tetrahedral and Trigonal Pyramidal

Lone Pair Electrons
A pair of electrons on an atom that are not involved in bonding.

Mass
A property of matter, which is a measure of the resistance to acceleration when force is applied
(Translation) A property of matter, which is roughly dependent on the amount of atoms within a physical object
Note: Compare to Weight

Mass Number
The total number of protons and neutrons in an atom of an element.
Note: Compare to Atomic Mass

Matter
Any physical substance, which occupied space and possesses mass
(Translation) Any physical substance, which is composed of atoms or molecules, that you can touch

Metallic
A type of bond, in which electrons migrate across a lattice of positively charged ions
(Translation) The attraction between an orderly arrangement of positively charged ions and a sea of mobile electrons
Note: Refer to Bond
Note: Compare to Covalent Bond and Ionic Bond
<table>
<thead>
<tr>
<th><strong>Molecular Geometry</strong></th>
<th>The three dimensional shape of a molecule, based on the arrangement of atoms around a central atom.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Note:</strong> Compare to <em>Molecular Symmetry</em></td>
<td></td>
</tr>
<tr>
<td><strong>Molecular Symmetry</strong></td>
<td>A quality of molecular geometry, which predicts molecular polarity. (Translation) Whether a molecule is symmetrical or asymmetrical, which determines whether the molecule is non-polar or polar</td>
</tr>
<tr>
<td><strong>Note:</strong> Refer to <em>Molecular Geometry and Polarity</em></td>
<td></td>
</tr>
<tr>
<td><strong>Molecule</strong></td>
<td>An uncharged group of atoms held together by covalent chemical bonds</td>
</tr>
<tr>
<td><strong>Network Covalent</strong></td>
<td>A type of molecule, in which all atoms are covalently bonded together in a rigid, repeating structure.</td>
</tr>
<tr>
<td><strong>Solid</strong></td>
<td>A subatomic particle with no charge found inside the nucleus of an atom that has a mass of 1 amu</td>
</tr>
<tr>
<td><strong>Neutron</strong></td>
<td>Note: Compare to Proton and Electron</td>
</tr>
<tr>
<td><strong>Non-polar</strong></td>
<td>A type of covalent bond, in which two atoms share their electrons almost equally resulting in a symmetrical distribution of electrons</td>
</tr>
<tr>
<td><strong>Note:</strong> Refer to <em>Covalent Bond</em></td>
<td></td>
</tr>
<tr>
<td><strong>Note:</strong> Compare to Polar</td>
<td></td>
</tr>
<tr>
<td><strong>Nucleus</strong></td>
<td>The dense positively charged mass at the center of the atom, which contains protons and neutrons.</td>
</tr>
<tr>
<td><strong>Observation</strong></td>
<td>The act of physically measuring the properties of a system</td>
</tr>
<tr>
<td><strong>Oxidation State</strong></td>
<td>An integer that represents the actual or hypothetical charge of an atom within a compound.</td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td>Related to matter</td>
</tr>
<tr>
<td><strong>Note:</strong> Refer to <em>Matter</em></td>
<td></td>
</tr>
<tr>
<td><strong>Physical (change)</strong></td>
<td>A change that only alters the appearance of a substance, such as switching physical states, but maintains identity of a substance, because the atomic structure is not rearranged (Translation) A change in appearance that does not transform one substance into another</td>
</tr>
<tr>
<td><strong>Note:</strong> Compare to <em>Chemical (change)</em></td>
<td></td>
</tr>
<tr>
<td><strong>Polar</strong></td>
<td>A type of covalent bond, in which two atoms share their electrons unequally, which results in an asymmetrical distribution of electrons. Sometimes considered an intermediate between non-polar covalent and ionic bonding. Can also refer to a polar molecule, which is a molecule with asymmetrical geometry and thus asymmetrical electron distribution.</td>
</tr>
<tr>
<td><strong>Note:</strong> Refer to <em>Covalent Bond, and Ionic Bond</em></td>
<td></td>
</tr>
<tr>
<td><strong>Note:</strong> Compare to <em>Non-polar</em></td>
<td></td>
</tr>
<tr>
<td><strong>Polarity</strong></td>
<td>A property of a molecule or a bond, which depends on the distribution of electrons.</td>
</tr>
</tbody>
</table>
(Translation) For bonds, a property that depends on the distribution of electrons as determined by the electronegativity of the two atoms. For molecules, a property that depends on the distribution of electrons due to both molecular symmetry overall and electronegativity of the individual atoms within the molecule.

**Note:** Refer to *Electronegativity* and *Molecular Symmetry*

**Polyatomic Ion**
A molecule of two or more covalently bonded atoms that carries a charge.

**Note:** Compare to *Ion*

**Potential (energy)**
The energy that an object possesses, because of its position, composition or condition.

**Note:** Compare to *Potential (energy)*

**Precipitate**
An insoluble solid that separates from a solution, which is the product of a chemical reaction between compounds or ions in the solution.

**Precision**
The correctness of a measurement or series of measurements based on the reproducibility of the measurement(s).

(Translation) How close a measurement is to repeated measurement of the same thing.

**Product**
A compound that is produced as the result of a chemical reaction.

**Note:** Refer to *Reaction*

**Reactant**
A compound that is transformed by a chemical reaction into a product.

**Note:** Refer to *Reaction*

**Reaction**
The chemical phenomenon where a substance(s) undergoes a chemical change by way of dissociation, recombination or rearrangement of atoms.

(Translation) A chemical change that produces a new substance.

**Note:** Refer to *Chemical (change)*

**Resonance**
The bonding behavior of a molecule that cannot be accurately or completely described with only one Lewis Structure, due to the existence of delocalized electrons within that molecule.

(Translation) The true state of the bonding behavior of a molecule, in which electrons do not form one discrete bond between two atoms, but exist as multiple partial bonds between two or more atoms.

**Note:** Refer to *Lewis Structure*

**Single Bond**
A type of covalent bond, in which two atoms share two electrons.
Note: Refer to *Covalent Bond*

**Single Replacement**
A type of chemical reaction, in which two reactants trade one substituent to form two new products.

**Solubility**
The ability of a substance, called the solute, to dissolve in a solvent to form a homogeneous solution.

**Spectroscopy**
The analysis of the interaction between electromagnetic radiation, such as light, and matter typically for the purpose of substance identification.

(Translation) The study of matter interacting with light

**Spectrum**
A range of wavelengths of electromagnetic radiation, often visible as colors, that can be used to identify a substance.

**Spin**
An intrinsic property of electrons that can be characterized as spin-up or spin-down, which causes magnetic phenomena similar to that of a spinning magnet.

**Stoichiometry**
A branch of chemistry that quantitatively counts the ratios of elements and compounds in chemical reaction. Ratios can refer to atoms or moles.

(Translation) A numerical system for tracking atoms in a reaction to ensure that mass is conserved

**Subatomic Particle**
A particle that is smaller than an atom, which makes up an atom

**Synthesis**
A type of chemical reaction, in which two or more compounds are combined into one compound.

**Temperature**
A measure of the intensity of heat

**Tetrahedral**
A molecular shape, in which the central atom has four substituents that are approximately 109° apart and no lone pairs of electrons.

**Trigonal Pyramidal**
A molecular shape, in which the central atom has three substituents that are approximately 109° apart and one lone pair of electrons.

**Triple Bond**
A type of covalent bond, in which two atoms share six electrons
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valence Electron</td>
<td>An electron that resides in the highest energy level of the atom, which can be actively involved in bonding</td>
<td>Refer to Bonding and Energy Level</td>
</tr>
<tr>
<td>Van Der Waals</td>
<td>A type of intermolecular force, that results from the movement of electrons. Includes dispersion forces and dipole-dipole interactions.</td>
<td>Refer to Intermolecular Forces and Dipoles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compare to Dispersion Forces</td>
</tr>
<tr>
<td>Wavelengths</td>
<td>The distance, usually in nanometers, between adjacent peaks on a wave, which determines the color of light.</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>The relative mass of a physical substance as it is related to the local gravitational pull.</td>
<td>Compare to Mass</td>
</tr>
<tr>
<td>(Translation)</td>
<td>The force of an object due to gravity, which is how heavy an object feels when you try to lift it</td>
<td></td>
</tr>
</tbody>
</table>
Symbolic Glossary for Mathematic and Chemical Symbols

Symbol Glossary for All Modules

*Singular Symbols*

\( \Delta \) Change or sometimes heat, when written in a chemical equation.

Change does not indicate a chemical change, but rather a change in the amount of something

\( \rightarrow \) Chemical Change (indicates a chemical reaction)

\( \uparrow \) or \( \downarrow \) Indicates directional spin of the electron, used in orbital notation

\( : \) Lone pair of electrons found in Lewis dot diagrams. Also called non-bonding electrons

\( - \) Indicates a single bond between atoms in Lewis dot diagrams or line-angle chemical structures (sometimes called skeletal).

\( = \) Indicates a double bond between atoms in Lewis dot diagrams or line-angle chemical structures (sometimes called skeletal).

\( \equiv \) Indicates a triple bond between atoms in Lewis dot diagrams or line-angle chemical structures (sometimes called skeletal).

\([X]\) Indicates the electron configuration of a noble gas, in which X is the elemental symbol of the noble gas

(I) Roman numerals within IUPAC Nomenclature indicates the oxidation state of the element they follow, and can be as low as I to as high as VII

(g) gaseous state

(l) liquid state

(s) solid state

E Energy

H Heat

d d orbital

e\(^-\) electron (sometimes shown as e)

f f orbital

n neutron (sometimes shown as n\(^0\))

p proton (sometimes shown as p\(^+\) to differentiate from p orbital)

p p orbital

p\(_x\) p sub-orbital

p\(_y\) p sub-orbital

p\(_z\) p sub-orbital

s s orbital
**Symbol Combinations**

- $\Delta E$  
  Change of the amount of energy
- $\Delta H$  
  Change of the amount of heat
- $\Delta H \rightarrow$  
  Indicates an endothermic reaction
- $\rightarrow \Delta H$  
  Indicates an exothermic reaction

**Models**

- **Dalton's Atomic model**
- **Thompson's Atomic Model, also called the Plum Pudding Model**
- **Rutherford's Atomic model, also called the Nuclear Model**
- **Bohr's Atomic Model, also called the Planetary Model**
- **Wave-Mechanical Atomic Model, also called the Modern or Quantum Model**

**Bright Line Spectrum**  
The spectrum of an incandescent substance that appears as a series of bright lines

**Continuous Spectrum**  
The spectrum of emissions from a substance across a continuous series of wavelengths. Sometimes depicted similarly to the bright line spectrum.
**Types of Symbol Notation**

**Atomic Symbol**
The combination of the elemental symbol with the mass number and the atomic number, and sometimes the charge. Also called the nuclear symbol.

(Looks like) \[ ^{A}M_{X}^{+/-} \]

(Example) \[ ^{2}He^{0} \]

where the ________ is the...

**Mass Number**
The total mass of that atom (protons plus neutrons)

(Looks like) \[ ^{A}_{M}X^{+/-} \]

**Atomic Number**
The total number of protons of that atom

(Looks like) \[ ^{A}_{M}X^{+/-} \]

**Elemental Symbol**
The alphabetical abbreviation of the name of an element, which can be found on the periodic table.

(Looks like) \[ ^{A}_{M}X^{+/-} \]

**Charge**
The electrical charge of the atom, which can be used to infer the number of electrons. Can be positive, negative or neutral.

(Looks like) \[ ^{A}_{M}X^{+/-} \]

**Chemical Equation**
A kind of chemical notation that describes the process of a chemical reaction by listing involved chemicals by molecular formula, with the reactants placed before the arrow and the products after the arrow.

(Looks like) \[ 2CH_{2} + 3O_{2} \rightarrow 2H_{2}O + 3CO_{2} + \Delta \]

where the ________ is the...

**Numerical Script**
The number of molecules for the following molecular formula

(Looks like) \[ 2CH_{2} + 3O_{2} \rightarrow 2H_{2}O + 3CO_{2} + \Delta \]

+ Indicates the chemical combination of the formulas around it

→ Indicates that a chemical change occurs

Δ Indicates the absorption of heat if placed before the arrow and the release of heat if placed after the arrow

**Decimal Notation**
The numerical system typically used in pure mathematics, which uses integers and a decimal point
Lewis Dot Structure  A diagram that depicts the valence electrons shown as dots around the elemental symbol of an atom

(Looks like) Na

Line-angle Structure  A diagram of a molecule that depicts bonds with lines and atoms with their elemental symbol. Also are called skeletal structures, and can be derived from Lewis Dot Structures

(Looks like)

\[
\begin{array}{c}
\text{H} \\
\text{O} \\
\text{H}
\end{array}
\]

Major Energy Level  The simplest notation type for electron configurations, in which only the numbers of electrons in each energy level are shown by increasing energy, separated by dashes.

(Looks like) 2 - 8 - 8

Molecular Formula  A kind of chemical notation that indicates the composition of a compound by listing the type of atoms with their elemental symbols and indicating the number of atoms.

(Looks like) \( \text{CO}_2^- \)

where the ________ is the...

Subscript  The number of atoms of the preceding elemental symbol

(Looks like) \( \text{CO}_2^- \)

Superscript  The overall charge of the compound or ion

(Looks like) \( \text{CO}_2^- \)

Noble Gas Notation  A simplified version of the spectroscopic notation type, in which all filled energy levels can be replaced by an abbreviation of the electron configuration for the associated noble gas

(Looks like) [He] 2s\(^2\) 2p\(^6\)

Orbital Notation  A more complex version of the spectroscopic notation type, in which electrons are represented with arrows to indicate their spin and suborbital location, instead of numerical values

(Looks like) ↑↓ 1s ↑↓ 2s ↑↓ 2p\(_x\) ↑↓ 2p\(_y\) ↑↓ 2p\(_z\)

Scientific Notation  The numerical system often used in chemistry, specifically for exceptionally large or tiny numbers, which uses powers of ten

(Looks like) \( 1 \times 10^5 \)

where the ________ is the...

Mantissa  The real number, also called the significand

(Looks like) \( 1 \times 10^5 \)
Base

The number that is going to be raised by the power
(The base is always 10 in scientific notation)

(Looks like) $1 \times 10^5$

Exponent

The raised power as shown by the superscript

(Looks like) $1 \times 10^5$

Significant Figures

The digits in a number (which can be in decimal or scientific notation) that are considered accurate. Said digits depend on the accuracy and reliability of the measuring device used.

Spectroscopic Notation

The most often used notation type for electron configurations, in which energy level, orbital and number of electrons within the orbital are indicated.

(Looks like) $1s^2 \ 2s^2 \ 2p^6$

where the ________ is the...

Numerical Script

The energy levels

(Looks like) $1s^2 \ 2s^2 \ 2p^6$

Letters (s, p, d or f)

The filled orbitals

(Looks like) $1s^2 \ 2s^2 \ 2p^6$

Superscripts

The number of electrons within an energy level and orbital

(Looks like) $1s^2 \ 2s^2 \ 2p^6$
Regents Reference Table Support #1: Links for Navigating Regents Reference Tables

Regents Reference Tables
Downloadable at http://www.kentchemistry.com/newRT.pdf

Student Tips for Using the Regents Chemistry Reference Tables

Regents Reference Table Support #2: Link to Interactive Online Periodic Table

Royal Society of Chemistry's Interactive Periodic Table Database
Found at http://www.rsc.org/periodic-table

Regents Reference Table Support #3: Etymological Analysis of Elemental Names

Etymological Analysis & Origins of the first 36 Elements of the Periodic Table

(1, H) **Hydrogen**  
Hydro + gen  
(Greek) Water former  
*Explanation:* When Hydrogen burns in the presence of oxygen, water is formed

(2, He) **Helium**  
Helios + ium  
(Greek) Sun element  
*Explanation:* Helium was first discovered in the spectrum of the sun

(3, Li) **Lithium**  
Lithos + ium  
(Greek) Stone element  
*Explanation:* Lithium was discovered in mineral compounds

(4, Be) **Beryllium**  
Beryllos + ium  
(Greek) Beryl element  
*Explanation:* Beryl is a precious green gemstone, which is often mistaken for emerald, that contains Beryllium

(5, B) **Boron**  
Borax + on  
(English) Borax element  
*Explanation:* Borax is a mineral, commonly used in some laundry detergents, that contains Boron.

(6, C) **Carbon**  
Carbo + on  
(Latin) Charcoal element  
*Explanation:* Charcoal is one of the forms of pure carbon.

(7, Ni) **Nitrogen**  
Niter + gen  
(Greek) Saltpeter former
Explanation: Saltpeter (or Niter) is a mineral, that has been used is fireworks for centuries. When Saltpeter is mixed with a carbon compound in the presence of oxygen, nitrogen gas is formed as one of the products.

(8, O) **Oxygen**  Oksys + gen (Greek) **Acid former**

Explanation: Acids and bases were once considered to always have an oxygen present. Today, we know that while oxygen is common in Bronsted-Lowry acida or basea, that Lewis acids and bases do not have to contain oxygen at all.

(9, F) **Fluorine**  Flure + gen (Latin) **Flux element**

Explanation: A flux is a cleaning agent used in metallurgy, which often contains fluorine.

(10, Ne) **Neon**  Neos + on (Greek) **New element**

Explanation: Neon was one of the last commonly occurring, non-radioactive elements to be discovered, which occurred in 1898.

(11, Na) **Sodium**  Soda + ium (English) **Soda element**

Explanation: (Name) Baking soda is a household cooking chemical that contains Sodium.  
Explanation: (Symbol) The symbol, Na, comes from the Latin word Natron, which is a sodium-containing salt that was used for mumification in ancient Egypt.

(12, Mg) **Magnesium**  Magnesia + ium (English) White **Magnesia element**

Explanation: Milk of Magnesia (or white magnesia) is a common medication that contains Magnesium.

(13, Al) **Aluminum**  Alum + ium (Latin) **Alum element**

Explanation: Alum is an ancient chemical, used in medicine, cosmetics, dye and even cooking ingredients, that contains Aluminum.

(14, Si) **Silicon**  Silica + on (Latin) **Silica element**

Explanation: Silica is a mineral, that you probably know better as flint, that contains Silicon.

(15, P) **Phosphorus**  Phos + phero + us (Greek) **Light bearing element**

Explanation: Certain forms of phosphorus are phosphorescent (somewhat similar to fluorescent), which means they emit light in the dark.

(16, S) **Sulfur**  Sulfur (Latin) **Sulfur**

Explanation: Sulfur has been known since ancient times as a pure substance with a fould scent. Think 'Sulfur and Brimstone'.

(17, Cl) **Chlorine**  Khloros + ine (Greek) **Greenish-yellow element**

Explanation: Chlorine is named after the color it appears in as a gas.

(18, Ar) **Argon**  A + ergon (Greek) **No work**

Explanation: Argon is an inert element, or in other words, it is inactive, doesn't react or 'do work'.

(19, K) **Potassium**  Potash + ium (English) **Potash element**

Explanation: (Name) Potash is a mixture of minerals, which are formed by soaking the ashes of plants (including wood) in a pot of water, that contains Potassium.  
Explanation: (Symbol) The symbol, K, comes from the Latin word Kalium, which was derived from the arabic word, alkali, for potash. Note that the word alkaline is also derived from alkali, because potash has a basic or alkaline pH.

(20, Ca) **Calcium**  Calcis + ium (Latin) **Lime element**

Explanation: Lime is a mineral, which can be formed by burning chalk, that contains Calcium.

(21, Sc) **Scandium**  Scandinavia + ium (English) **Scandinavia element**
Explanation: Scandium was found and discovered in Scandinavia in 1879.

(22, Ti) **Titanium**  
**Titan** + ium  
**Titan** element  
Explanation: Titanium was named after the Titans, demi-gods from Greek mythology with incredible strength, because of Titanium's strengths as a metal.

(23, Ti) **Vanadium**  
**Vanadis** + ium  
**Vanadis** element  
Explanation: Vanadium was named after Vanadis, a Norse Goddess known for her beauty, because of the beautiful colored compounds that Vanadium forms.

(24, Cr) **Chromium**  
**Khroma** + ium  
**Color** element  
Explanation: Chromium is named for the many different colors of its compounds.

(25, Mn) **Manganese**  
**Magnesia** + ium  
**Black Magnesia** element  
Explanation: Black Magnesia is a mineral that contains Manganese.

(26, Fe) **Iron**  
**Iron** (Old German/English)  
**Iron** element  
Explanation: (Name) Iron is a metallic element known since ancient times.  
Explanation: (Symbol) The symbol, Fe, comes from the Latin word, Ferrum, for iron.  
Additionally, compounds of iron also use the derivation of Ferrum, such as Ferrous or Ferric.

(27, Co) **Cobalt**  
**Kobold** (Old German)  
**Dwarf** element  
Explanation: Cobalt, a metal mined from ore, is named after the dwarves of German mythology who were miners.

(28, Ni) **Nickel**  
**Nickel** (Old German)  
**Demon** element  
Explanation: Nickel, also a metal mined from ore, is named after demons of German mythology who lived in mines and stole precious metal from miners.

(29, Cu) **Copper**  
**Cuprum** (Latin)  
**Copper** element  
Explanation: Copper is named after the roman city, Cuprum, now better known as Cyprus, where copper was supposedly first mined. The atomic symbol is also derived from Cuuprum.

(30, Zn) **Zinc**  
**Zink** (German)  
**Zinc** element  
Explanation: Zinc is a metallic element known since ancient times.

(31, Ga) **Gallium**  
**Gaul** + ium  
**France** element  
Explanation: Gallium was discovered in France in 1875, thus its name was derived from the ancient word for France.

(32, Ge) **Germanium**  
**Germany** + ium  
**German** element  
Explanation: Germanium was discovered in Germany in 1886.

(33, As) **Arsenic**  
**Arsenikos** (Greek)  
**Brave** element  
Explanation: Copper weapons were made harder by adding arsenic, thus making Greek warriors more brave in battle.

(34, Se) **Selenium**  
**Selene** + ium  
**Moon** element  
Explanation: Selenium is named for its pretty moon-like luster.

(35, Br) **Bromine**  
**Bromos** + ium  
**Stench** element  
Explanation: Bromine is named for its recognizable smell.

(36, Kr) **Krypton**  
**Kryptos** + on  
**Hidden** element  
Explanation: Krypton, like Neon, was one of the last commonly occurring, non-radioactive elements to be discovered, which occurred in 1898.
### General Appendix

**Table #1:** Combination of Markow & Lazlo's chemistry and language analogy

<table>
<thead>
<tr>
<th>Chemistry Term</th>
<th>Chemical Representation</th>
<th>Analogous Language Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic symbol</td>
<td>One atom of one element</td>
<td>A letter in the alphabet</td>
</tr>
<tr>
<td>R group formula</td>
<td>Combined atoms of one or more elements in a functional group or substituent</td>
<td>A diphthong or syllable, suffix or prefix</td>
</tr>
<tr>
<td>Chemical Intermediate Formula</td>
<td>Combined atoms of one or more elements in a transitional state</td>
<td>A word root or &quot;parent&quot; word</td>
</tr>
<tr>
<td>Molecular Formula</td>
<td>Combined atoms of one or more elements in a molecule or compound</td>
<td>A word</td>
</tr>
<tr>
<td>A chemical equation (stoichiometrically balanced)</td>
<td>A reaction, or chemical change, occurring between multiple molecules, compounds and/or elements</td>
<td>A sentence (written with proper grammar)</td>
</tr>
<tr>
<td>IUPAC nomenclature &amp; structural projections</td>
<td>Analogous to molecular formula, a different way to represent a molecule or compound</td>
<td>Different dialects of one &quot;parent&quot; language</td>
</tr>
</tbody>
</table>

**Table #2:** Typical units as used in NYS Regents Chemistry classrooms

<table>
<thead>
<tr>
<th>Unit #1: Matter &amp; Energy (NOS)</th>
<th>Unit #2: Atomic Structure</th>
<th>Unit #3: Periodic Table (Electrons)</th>
<th>Unit #4: Bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit #5: Compounds</td>
<td>Unit #6: Reactions (Moles)</td>
<td>Unit #7: Solutions</td>
<td>Unit #8: Gases</td>
</tr>
<tr>
<td>Unit #9: Solids &amp; Liquids</td>
<td>Unit #10: Thermodynamics</td>
<td>Unit #11: Equilibrium</td>
<td>Unit #12: Kinetics</td>
</tr>
<tr>
<td>Unit #13: Acids, Bases &amp; Salts</td>
<td>Unit #14: Organic Chemistry</td>
<td>Unit #15: Redox Electrochemistry</td>
<td>Unit #16: Nuclear Chemistry</td>
</tr>
</tbody>
</table>
Table #3: Comparison of Jacob's chemical language levels & Common Core language levels

Table #4: Criss' Revision of the Chemical Language Analogy

<table>
<thead>
<tr>
<th>Chemical Concept</th>
<th>Example</th>
<th>Analogous Linguistic Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>An Atom of an Element</td>
<td>Oxygen - O₂</td>
<td>A letter in the Alphabet</td>
</tr>
<tr>
<td>The Electron Configuration of an Element</td>
<td>1s² 2s² 2p⁴</td>
<td>Phonetic pronunciation of a letter in the alphabet (indicates how it will 'fit' with other letters)</td>
</tr>
<tr>
<td>A functional group or substituent</td>
<td>-OH (Alcohol group)</td>
<td>A diphthong, digraph or syllable</td>
</tr>
<tr>
<td>A molecular formula</td>
<td>CH₃OH</td>
<td>A word</td>
</tr>
<tr>
<td>A chemical equation</td>
<td>CH₃OH + O₂ Δ → CO₂ + H₂O</td>
<td>A sentence</td>
</tr>
<tr>
<td>Stoichiometric balance of equations</td>
<td>CH₃OH + O₂ Δ → CO₂ + H₂O</td>
<td>Proper grammar</td>
</tr>
<tr>
<td>Formulas, IUPAC nomenclature &amp; structural projections</td>
<td>Methanol, Wood Alcohol</td>
<td>Different dialects (of words) within a language</td>
</tr>
<tr>
<td>A chemical intermediate &amp; substituent</td>
<td></td>
<td>An etymological word root</td>
</tr>
<tr>
<td>Unit Subject</td>
<td>Module Focus</td>
<td>Chemical Concepts</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Unit #1: Energy &amp; Matter</td>
<td>Resource navigation skills (specialized glossary, Table C, D &amp; T)</td>
<td>General scientific terminology &amp; conversions</td>
</tr>
<tr>
<td>Unit #2: The Atom</td>
<td>Reading &amp; navigating the periodic table (Table S)</td>
<td>An Atom of an element</td>
</tr>
<tr>
<td>Unit #3: The Electron</td>
<td>Depicting Electrons in models or notation</td>
<td>Electron Configurations</td>
</tr>
<tr>
<td>Unit #4: Bonding</td>
<td>Determining how atoms combine, based on valence electrons</td>
<td>Bond Types</td>
</tr>
<tr>
<td>Unit #5: Compounds</td>
<td>Writing compound formulas and depicting molecular models (Table E)</td>
<td>Compounds (Ionic &amp; Covalent)</td>
</tr>
<tr>
<td>Unit #5b: The Mole</td>
<td>Resource navigation skills (specialized glossary)</td>
<td>Mole Calculations</td>
</tr>
<tr>
<td>Unit #6: Reactions</td>
<td>Decoding &amp; Encoding Balanced Chemical Equations</td>
<td>Types of Chemical Reactions</td>
</tr>
<tr>
<td>Unit #7: Solutions</td>
<td>Resource navigation skills (Table F &amp; G)</td>
<td>Solubility of compounds, Concentration Calculations</td>
</tr>
<tr>
<td>Unit #8 &amp; 9: Gases, Solids &amp; Liquids</td>
<td>Resource navigation skills (Table A, B &amp; H), Calculations, Decoding &amp; Encoding Diagrams</td>
<td>Phase Changes, Gas laws</td>
</tr>
<tr>
<td>Unit #10 - 12: Thermodynamics, Equilibrium &amp; Kinetics</td>
<td>Resource navigation skills (Table I)</td>
<td>Heat of Reaction &amp; Reaction Rate Calculations</td>
</tr>
<tr>
<td>Unit #13: Acids, Bases &amp; Salts</td>
<td>Resource navigation skills (Table K, L &amp; M); Review of writing chemical equations</td>
<td>pH &amp; Titration Calculations, Acid Base Reactions</td>
</tr>
<tr>
<td>Unit #14 Organics</td>
<td>Resource navigation skills (Table P, Q &amp; R); Naming Chemical Compounds</td>
<td>IUPAC Nomenclature, Organic Reactions</td>
</tr>
<tr>
<td>Unit #15: Redox &amp; Electrochem</td>
<td>Resource navigation skills (Table J); Writing &amp; Balancing Redox Equations</td>
<td>Redox Reactions, Oxidation State Calculations</td>
</tr>
<tr>
<td>Unit #16: Nuclear</td>
<td>Resource navigation skills (Table N &amp; O); Decoding &amp; Encoding Nuclear Reactions</td>
<td>Nuclear Decay Reactions, Half-life Calculations</td>
</tr>
</tbody>
</table>

Italics indicate which units do not have a unique module, and that a previous module can be used.
Table #6: Comparison of Jacob's chemical language levels & scalar realms of chemistry
References


