Summer 2004

The Periodic Table of the Elements

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ABSTRACT

THE PERIODIC TABLE OF ELEMENTS

by

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June, 2004

The blueprint to the world of chemistry is encoded in the periodic table of the elements. This fundamental chart can be found in virtually all science classrooms in the world. The purpose of this project was to design a professional development course focusing on the periodic table of the elements. The target audience is college students working towards teaching science as a career, current teachers looking to enhance their understanding of the table, and resident teachers working towards continuing certification. In order to accomplish this purpose extensive literary research, the Washington State Academic Learning Requirements for science, published science lessons, and chemistry textbooks were all evaluated, reviewed, and utilized. Additionally, numerous other related sources of research were collected and reviewed. The activities presented are designed to provide an historical development of the table, hands-on laboratory activities investigating the properties of elements, and practical application of the table for introductory use in the classroom.

ACKNOWLEDGMENTS

I would like to express my appreciation to all the graduate professors whose courses I have enjoyed throughout my program at Central Washington University. I would especially like to thank Dr. Nourse and Dr. Chapman for their leadership and guidance on this non-thesis/project.

I would also like to thank my immediate family, who has literally put their lives on hold for the last three years as I have worked through the program. My daughters Katie, Elizabeth, and Rebecca have sacrificed quality story time and play time with dad, and my sons Warren and Michael have been left in charge of the little girls far too many times. Finally, I would like to thank my wife, Dana whose love, support, and editing skills have allowed me to succeed.

I would like to dedicate this project and the completion of my Masters Degree to my parents, Chan and Jeanne. It was the tough decisions that my parents made when I was growing up that has allowed me to become the person I am today. They sacrificed so that I would have a chance to be successful in life; they taught me the importance of an education.

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CHAPTER I

INTRODUCTION

"The periodic table of the elements, or the Mendeleev Chart, is the starting point for chemistry and critical for learning physics as well." (Hill, Lederman, 2001).

"The periodic table...relates in non-threatening ways to everyone's lives." (Carrado, 1993).

"Chemistry without the periodic table is as hard to imagine as sailing without a compass." (Rouvray, 1994).

The above statements strongly support the importance of the periodic table of elements as a crucial tool to utilize in chemistry and other fields. The importance of the periodic table to chemistry is further explained by Rouvray. He ascertains that Mendeleev's ideas changed chemistry forever, and how the development of the table would provide the necessary unity to continue the investigation of all matter in our universe. The elements finally had a location that would provide identification by two conventions, physical and chemical properties, and similar properties in relationship to each other, called periodicity (Treptow, 1994). Mendeleev's initial table also accurately predicted the identification and location of several elements that were undiscovered at the time of its initial publication in 1869, and to this day, additions continue to be made. Since the publication of the initial periodic table about 135 years ago, changes have been made to the table to support the addition of new elements, periodic groups, and a greater understanding of our physical world.

As we move into the twenty-first century, the scientific community continues to pursue new elements and make predictions on the future configuration of the periodic table. As the periodic table, referred to as the Mendeleev-Werner-Bohr-Seaborg table, starts to push towards the addition of an eighth row, scientists will continue to question how much further it might grow. Concepts related to nuclear stability, fission, and gravity will ultimately help determine the future table, and what will have to be done to support the new elements created or discovered (Karol, 2002).

Rationale

A number of science textbooks tend to individualize concepts without conceptually synthesizing them into one picture. Wound in the periodic table itself are a vast array of chemical stories waiting to be told, stories of atomic structure, the earth, planets, stars, and molecules of life. It is *these* stories that rarely come out in a standard science textbook. A momentary look at the periodic table can provide more than just relationships between elemental families and periods. A person who truly grasps the periodic table can begin to predict and understand chemical formulas, outcomes of chemical reactions, atomic structure, and patterns (Timmreck, 1991).

Teachers who have this grasp of the periodic table can utilize its power to support the majority of the concepts approached in a science classroom. The periodic table is more than just a table of technical information; it is the story of the atom, the fundamental entity of our physical world.

Purpose

The purpose of this project was to design a professional development course focusing on the periodic table of the elements. The target audience for the course is middle school and high school science teachers. At the completion of the course the material and knowledge gained can be implemented independently or with any currently existing science curriculum. The activities presented are designed to provide an historical development of the table, elemental relationships, hands-on laboratory activities investigating the properties of elements, and practical application of the table for introductory use in the classroom. The activities have a direct connection to the Washington State Essential Academic Learning Requirements (EALR) (Commission on Student Learning Requirements, 1999).

Limitations of the Project

For the purposes of this project, it was necessary to set the following limitations:

1. *Research*: No drastic changes have been made to the table in over 40 years thus information related to it history is entrenched deep in the past. For the purpose of this paper research did not have a time limitation. The majority of the current information provides only a summary of changes and does not provide the in-depth reasoning behind those changes.
2. *Literature*: The scope of this paper requires that the literature be limited to a review of relevant factual information about the origin and application of the periodic table. This paper will not attempt to review the literature that is embedded deep in scientific research other than a summary of results. Although a great number of current journal articles were collected, there is an apparent lack of availability of critical journal articles written prior to the 1960's. Given this void, research was conducted using specialty books written on the periodic table. These in-depth books appear to have been written by the leading scientists in the field of the periodic table.
3. *Scope*: This project was designed to be used by teachers from the middle grades up to high school chemistry classes. Special consideration was given

to teachers who have a minimal or limited education in the field of chemistry when this project was put together. Available information on the periodic table is very vast and often overwhelming for those who have little background in chemistry. It was the writer's (Michael A. Bailey) desire to help summarize this information into a practical tool that can be utilized by virtually any teacher.

The project was centered on the science concepts in accordance with the EALR's for benchmark grades eight and ten. The knowledge gained by this project can easily be integrated into other fields of science, history, and mathematics. It is important for the students to engage in work that is meaningful to them and this project was designed to help students develop a love for science and further encourage the concept of life-long learning.

Definition of Terms

1. *Actinides (actinoides)* – the series of elements from actinium (89) to nobelium (102).
2. *Alchemy (alchemical)* – the practice of trying to change base metals into gold or silver. (A Concise Dictionary of Chemistry, Oxford Press, 1996).
3. *Atomic Theory* – the theory that all material objects are made of atoms.
4. *Atomic Weight (relative atomic mass)* – the ratio of average mass per atom compared to H = 1, O = 16, or C = 12.
5. *Elements*: A substance that cannot be decomposed into simpler substances. The elements are grouped into families and periods instead of individuals, although some individual elements are mentioned, most are not discussed in detail.

6. *Electron Configuration* – the organization structure which incorporates the use of *s,p,d,* and *f* regions of the atom. It is used to explain how the electrons fill the region around the atoms nucleus. (A Concise Dictionary of Chemistry, Oxford Press, 1996).
7. *Equivalent Weight* – The mass of an element or compound that could combine with one gram of hydrogen. Represents the 'combining power' of the atom. For an element it is atomic mass divided by its valency. (A Concise Dictionary of Chemistry, Oxford Press, 1996).
8. *Homologous* – a series of elements or compounds of which each member has a structure differing regularly by some even increment.
9. *Lanthanides (lanthanoids, lanthanons, rare earth elements)* – the series of elements from lanthanum (57) to ytterbium (71).
10. *Mendeleev* – various spellings have been used to identify the father of the periodic table. Mendeleev was how he signed his name in English but Mendeleyev, Mendeleiev, Mendeleieff, Mendeleyeff, and other variants have been used (Strathern, 2000).
11. *Metaphysics* – the branch of philosophy that deals with first principles and seeks to explain the origin and structure of the world. (A Concise Dictionary of Chemistry, Oxford Press, 1996).
12. *Nomenclature* – a set of names used to differentiate between different elements and compounds.
13. *Periodic System (periodic table, periodic law, periodicity)*: the system of classification of the elements. *Periodic law* is based upon the arrangements

according to atomic weight. *Periodic table* is based upon the arrangement according to atomic number. This project will only use the two-dimensional quantum mechanic model of the table (*s*, *p*, *d*, *f*), the Mendeleev-Werner-Bohr-Seaborg table will be investigated and used. This is the most common table in use today in the United States. (A Concise Dictionary of Chemistry, Oxford Press, 1996).

14. *Quantitative Analysis* – the numeric means used to identify the behavior of the elements. Example: Magnesium reacted with oxygen in a ratio of 1:1.
15. *Qualitative Analysis* – the verbal means used to identify the behavior and separate the elements. Example: Magnesium would react with oxygen.
16. *Quantum* – the minimum amount by which certain properties, such as energy or angular momentum, of a system can change. (A Concise Dictionary of Chemistry, Oxford Press, 1996).
17. *Transactinides (transfermium elements)* – elements with an atomic number greater than 103.
18. *Transition Elements* – the elements in the middle of the table that form the *d*-blocks and *f*-blocks.
19. *Triads, Tetrads, Pentads* – repeating groups of three, four, and five.
20. *Transuranic Elements* – elements with an atomic number greater than 92.
21. *Valency (Valence)* – the combine power of an atom or ion, equal to the number of hydrogen atoms that the atom could combine with in a chemical compound. (A Concise Dictionary of Chemistry, Oxford Press, 1996).

Summary

It is the intent of this paper to provide an introduction to the periodic table of elements. The goal is also to help build an historical view of the changes that have occurred in science and how that history has molded the table used today. The lessons and activities provide the students the opportunity to explore, question, and draw conclusion about the world around them and open the doors for further discovery and understanding. The following chapters will discuss the literature review, procedures, the project curriculum and activities, the summary of the project, conclusions and recommendations, and bibliography.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

As a result of reviewing the literature, it was found that the inclusion of the history of science into the curriculum provides a meaningful perspective to scientific concepts. The historical development of the periodic table is a journey of chemical understanding that parallels the systematic journey into the atom. The literature also reflected how the periodic system serves as a classification system and as a conceptual tool which has helped make elemental predictions, reflected unrecognized relationships, served as a corrective device, and has provided an organization device (Spronsen, 1969). The periodic system is applicable to many science disciplines and is fundamental to the chemistry classroom. A basic understanding of the periodic table will provide any teacher, regardless of grade level, a foundation to support his or her science curriculum. It is the intent of this project to provide useful and pertinent information and include sample activities directed towards understanding and using the periodic table by teachers. This project specifically targets the integrated science program seen at the eighth, ninth and tenth grade levels, but it can be useful to all other grade levels as well.

It is important to mention how well these ideas will support the Washington State Essential Academic Learning Requirements (EALR). Benchmark three for grade ten under physical science states, *Examine the basis for the structure and use of the periodic table*, and benchmark three grade ten under physical science also states, *Know that science involves testing, revising, and occasionally discarding theories; understand that scientific inquiry and investigation lead to a better understanding of the natural world* *and not to absolute truth.* Benchmark three for grade ten under All Peoples Contribute to Science and Technology states, *Analyze how scientific knowledge and technological advances discovered and developed by individuals and communities in all cultures of the world contribute to changes in societies* (Commission on Student Learning Requirements, 1999).

The review of literature has been organized into several major topics:

I. Use of History in Science Curriculum

II. The History of the Tables Development:
    a. Element vs. Atom
    b. Quest for Atomic Weight
    c. Early Attempts at a Periodic System
    d. The Periodic Law

III. Major Changes to the Table:
    a. The Noble Gases
    b. The Rare Earths
    c. The Discovery of Atomic Structure
    d. Isotopes
    e. The Transactinide Series

IV. International Union of Pure & Applied Chemistry (IUPAC)

V. Location Problems on the Table

VI. Beyond the Current Table

Use of History in Science Curriculum

History is typically associated as a distinct academic discipline in most secondary schools and its relevance to understanding science concepts is often underrated. Heilbron (2002) expressed the importance of incorporating history into science education curriculum and stated that there are essentially two reasons as to why most consider it to be more of a *sugar coating* instead of real curriculum. The first being, science teachers have not made the history of his or her discipline a significant part of his or her pedagogical work. Secondly, textbook writers have failed to incorporate history into work, often this is a result of the demands placed on the writers.

Heilbron (2002) provided three literary examples of how some of our greatest scientists wrote about and benefited from a historical approach to science material. (1) Max Planck and Albert Einstein studied and profited from Ernst Mach's *Die Mechanik in ihrer Entwicklung, historisch-kritish dargetstellt* (1883). (2) Joseph Priestley wrote *History and Present State of Electricity* (mid-18th century) which laid out the course of discovery for all electrical knowledge. Priestley's book had five editions and several translations which highlights its importance to the science world. Finally, Max Born's book, *Die Relativitatstheorie Einstein's* (1920), still offers a historically-critical approach to understanding Einstein's theory of relativity.

Wang and Marsh (2002) conducted a study that investigated the perceptions and practices of elementary and secondary teachers in using the history of science in his or her classrooms. The framework was centered on three realms: 1) conceptual understanding, 2) procedural understanding, and 3) contextual understanding. The study (N = 37) included a questionnaire that used a Likert scale and a small sub-group of teachers were interviewed. The survey and interview data were able to delineate eight key themes:

1. *Teachers who believe in and practice the inclusion of the history of science introduce the notion that science is a human endeavor and scientists are human like the rest of us.*
2. *Teachers who believe in and practice the inclusion of the history of science reinforce the idea that scientific research requires intrinsic motivation as well as extrinsic motivation.*
3. *Teachers who believe in and practice the inclusion of the history of science help students understand how social factors or political power are closely related to scientific endeavors.*

4. *Teachers who believe in and practice the inclusion of the history of science help students understand that scientists also work in a community where new knowledge is built on other people's endeavors.*
5. *Teachers who believe in and practice the inclusion of the history of science help students recognize diverse cultural heritages and role models.*
6. *Teachers believe the inclusion of the history of science can be a powerful tool but not for elementary students.*
7. *Teachers perceive some benefits of the historical element for the Procedural Understanding Realm, but found it difficult to practice this.*
8. *Teachers believed there are too many topics to be covered in the curriculum. The historical elements were introduced only when they could be blended in their current instruction.* (pgs. 183 – 186).

Wang and Marsh (2002) felt that humanizing science was more than just "making it fun" but making it a human and meaningful endeavor. Support for this idea is stated by the National Science Education Standards (NSES) which states that an historical approach will "elaborate various aspects of scientific inquiry, the nature of science, and science in different historical and cultural perspectives" (NRC, 1996, p. 200).

The inclusion of history into our curriculum will enrich the learning experience and bring scientific figures into individual experiences. The next section will begin our historical journey of periodicity and lay the foundation for Mendeleev to build upon.

The History of the Tables Development:
Element vs. Atom

Spronsen (1969) pointed out that in order for periodicity of the elements to have been established, three important components would have had to be in place. First, a large number of elementary substances (elements) would have to be known. Secondly, these elementary substances need to be clearly expressed in terms of quantitative values, equivalent weights; this would provide the so-called horizontal connection needed for the table. Lastly, the elementary substances would have to have a qualitative connection that would result in the building of series, groups, and families based upon physical and chemical properties, this would provide the so-called vertical connection needed for the table. Once all three of these components were in place, scientists were able to put together the first tables. This section is going to investigate the philosophers, scientists and discoveries that would define the elements and bring about the qualitative connections. The complete story of the discovery, qualitative data, and historical application of the elements would take us beyond the scope of this paper. It is necessary, however, to investigate the theories and discoveries that occurred in the scientific world prior to the development of Mendeleev's first table in 1869, and to highlight some key philosophers, scientists, and his or her individual contributions.

Research conducted by Paul Strathern (2000) placed the starting point for Mendeleev's periodic system about 2500 years earlier in ancient Greece, the very origin of scientific thought. Human thought was beginning to take a closer look at the world and superstition and metaphysics were being pushed aside for a more in-depth clarification. The first theory (the theory of elements) to arise was the four-element (earth, water, air, and fire) theory by Empedocles, who lived in Sicily during the fifth century B.C. It should be noted that Empedocles was strongly influenced by his teacher Pythagoras (who is regarded as one of the greatest mathematicians of all time). This theory of elements was adopted and built upon by the great Athenian philosopher Socrates around 450 ^{BC}, Socrates was succeeded by his pupil Plato, but it was Plato's student Aristotle that would affect the world for years to come and his idea that the four-elements were more of qualitative in nature instead of quantitative.

Strathern's (2000) research pointed out that at about the same time that Empedocles derived his theory of elements Leucippus asked the question 'Is matter discrete or continuous'? "In other words, is it possible to go on dividing things up indefinitely or does one reach a point where things become indivisible?" (p. 21). Leucippus answer to the question was the later, and this led him to the idea of the *atomos*, Greek for 'uncuttable'. Leucippus provided the world the first atomic theory. Leucippus pupil was Democritus who would further expanded upon his teachers idea. Spronsen (1969) stated that Democritus believed that it was the motion of these atoms that accounted for the changes in matter. With this idea were two problems; the first is that Democritus assumed the number of atoms was not limited and lastly he neglected the weight of the atoms. At this time it was Epicurus who attribute the mass of an object to it atoms. "Neither Epicurus nor Democritus, however, related their atomic theory to an existing or new theory of elements." (p. 16). It was this reason that no headway was accomplished in applying both the theory of elements of Aristotle and the atomic theory of Democritus to natural changes that occurred in matter. The four-element system was considered to be the better of the two to explain changes seen in matter and ultimately it was used exhaustively. "Conversely, the notion that the world consisted of four elements was like a disease, and it was to cripple scientific thinking for the next two millennia." (p. 17).

According to Spronsen (1969) the atomic theory was not forgotten and it was able to keep up with the theory of elements for the next two thousand years. Early scientists like Francis Bacon and David van Goirle (corpuscular theory), Van Helmont (two-element theory), Sennert (theory of the immutability of elementary particles), and the 16th century alchemist Paracelsus (three-element theory) all provided the foundation for Robert Boyle to build upon in seventeenth century.

Robert Boyle did not accept the concept of Aristotle's' elements and he developed a technique to break down substances into their most basic parts (Holden 2004). Spronsen (1969) mentioned the following about Boyle:

> According to him, every element has its special kind of atom, though each composed of the same primary substance. The difference between atoms was due to form, size, and pattern of motion. Boyle called a combination of smallest particles of the same kind *texture* and a combination of particles of different kind's *mixture*. Both results in what researchers know call molecules of an element and molecules of a compound. (p. 17).

Holden (2004) stated that Boyle's definition of an element was *material that could be identified by scientific experiment and could not be broken down into simpler substances*. Spronsen (1969) pointed out that Boyle's short falling was that he did nothing to contribute to the investigation of the elements. He did not mention them by name and made no addition to the number of possible elements. Boyle's work also provided an initial system of classification that used the classic terms class, genius, and species. The foundation behind Boyle's system of classification was the physical and chemical properties observed during his time. "He classed metal as a genus or gender and, for instance, silver and gold as species, but when he considered the metals with respect to *mixed bodies*, i.e., the compounds, Boyle called them species relative to the so-called *fossilia*." (p. 27). The eighteenth century would see a series of scientist build upon Boyle's classification system, Carolus Linnaeus, Torbern Bergman, Georges Louis Buffon, Guyton de Morveau, Claude Louis Berthollet, Antoine Francois de Fourcroy and then Antoine Laurent de Lavoisier who would published his book *Methode de*

Nomenclature chemiique in 1787. This work provided the beginning point of chemical nomenclature. According to Emsley (1989) Lavoisier also defined the chemical element as something which could not be broken down further and he classified the elements into four different categories; the gases, the non-metals, the metals, and the earths.

> Another of Lavoisier's brilliant contributions to chemistry was to advocate that chemicals should be named after the elements of which they were composed. This de-mystified the language of chemistry of its alchemical names, and the result was the chemicals like "butter of antimony" became antimony chloride, and 'lunar caustic' became silver nitrate. (p. 263).

Strathern (2000) mentioned that the practice of alchemy did provide a few elements during the seventeenth century and many useful applications of our physical world, i.e. stronger weapons, better tools, gun powder, and etc., but in the end "The path of alchemy led to lunacy – not only for chemistry." (p.186).

Emsley (1989) provided a break down of the elements identified up to the end of the eighteenth century:

Elements Known to the Ancients:

1. *Carbon* (charcoal left over from fire).
2. *Sulfur* (volcanoes)
3. *Copper* (first metal to be worked 5000 ^{BC})
4. *Gold* (first produced ≈ 3000 ^{BC})
5. *Silver* (first produced ≈ 3000 ^{BC})
6. *Iron* (smelting – Iron Age ≈ 2500 ^{BC})
7. *Tin* (≈ 2100 ^{BC})
8. *Mercury* (≈ 1500 ^{BC})
9. *Lead* (≈ 1000 ^{BC})
10. *Antimony* (≈ 1600 ^{BC})

Dark Ages (fall of Rome in ^{AD} 410) to the year 1700:

11. *Arsenic* (13th Century – alchemy contribution)
12. *Bismuth* (15th Century – alchemy contribution)
13. *Zinc* (15th Century)

14. *Phosphorus* (17th Century – alchemy contribution). The discovery of this element is seen as the turning point between alchemy and chemistry.
15. *Platinum* (18th Century)

<u>The Eighteenth Century Elements:</u>

16. *Cobalt* (1735)
17. *Nickel* (1751)
18. *Magnesium* (1755)
19. *Hydrogen Gas* (1766)
20. *Oxygen* (1772 – Scheele and 1774 – Priestley) – it was the discovery of oxygen and hydrogen gas from water that delivered the greatest blow to Aristotle's four-elements. It proved that water was not an element.
21. *Nitrogen Gas* (1772)
22. *Manganese* (1774)
23. *Chlorine* (1774)
24. *Chromium* (1780)
25. *Molybdenum* (1781)
26. *Tellurium* (1783)
27. *Tungsten* (1783)
28. *Zirconium* (1789)
29. *Uranium* (1789)

Strathern (2000) explained that Antoine Lavoisier provided the basis behind our current nomenclature system and he was one of the first to organize the elements into specific groups based upon chemical and physical properties, this would ultimately provide the qualitative connection needed for the periodic system. As great as his contribution was in the area of elemental classification, it would be his contribution to the quantitative aspects of chemistry that labeled him, by many, as the father of modern chemistry.

> Lavoisier operated on the principle that the substance taking part in a chemical reaction could be transformed, but their overall weight would always remain the same. This had been the secret of his discovery that water boiling in a flask does not produce earth. It is this which is behind the law of conservation of matter. This basic assumption of Lavoisier's

> experiments was to become one of the cornerstones of nineteenth-century chemistry. (p. 235).

The next section will focus on the quantitative connections, the establishment of a molecular theory, and atomic weights.

The History of the Tables Development: Quest for Atomic Weight

Emsley (1989) indicated that it was John Dalton with his atomic theory and Law of Fixed Proportions, which would initiate the intellectual revolution that started the 19th Century boom in scientific discoveries. Strathern (2000) wrote that Louis-Joseph Proust stated in his *Law of Definite Proportions* that all compounds consist of elements in definite simple ratios by weight. Dalton recognized the implication of these particles, and Boyle's tiny indivisible particles, with Democritus' idea of the 'uncuttable' *atomos,* and it would be Dalton that decided to call them atoms. Unlike Democritus whose concept of the atom was theoretical, Dalton's atom was scientific and practical. Dalton's atoms were purely concerned with weight. Although at the time there was no way to determine actual weight of atoms, it was possible to determine relative weights as they occurred in compounds (Law of Fixed Proportions). "Dalton's was a quantitative theory which combined Democritus' original concept with Lavoisier's application of quantitative measurement to chemistry." (p. 245).

Strathern (2000) added, "This momentous idea transformed our understanding of matter. During the two centuries following its discovery, science was to progress beyond all imagining." (p. 245). Spronsen (2000) stated the importance of Dalton's atomic theory, "After Dalton's atomic theory had been formulated; an element was described as a collection of atoms of the same kind. Furthermore, each element was characterized by a specific number, i.e. the atomic weight of identical particles. At last, the old controversy of element versus atom had been eliminated." (p. 13).

Holden (2004) stated that Dalton is usually given credit for the first atomic theory to be established on sound experimental basis. Dalton assigned weights to atoms and would express the relationship to atoms in precise numerical terms. He would incorporate the use of hydrogen = 1, for his standard and proceeded to compare all other elements with that of hydrogen. Dalton would publish the first table of atomic weights in a paper entitled, *On the Absorption of Gases by Water and Other Liquids*. It was read to the Manchester Literary and Philosophical Society on October 21, 1803; but not published until 1805 because Dalton had some doubts as to his values for some elements.

Spronsen (1969) acknowledged that Dalton was only able to determine a small number of atomic weights, but in theory it was possible to determine the atomic weights of other elements. Spronsen (1969) further explained the problem, "But the greatest difficulty was the persistent lack of the concept now called valence. Until this concept had been formulated and applied, it remained impossible to differentiate between atomic and equivalent weights." (p. 44).

Holden (2004) explained the problem as well:

> When two elements combine in a compound, it is insufficient to merely determine the percentage of each element present to obtain the correct atomic weight. One must also determine the valence of each element in the compound. Valence is a measure of how many atoms of one element combine with an atom of the other element, e.g., is water HO or H2O or perhaps H2O2? Unfortunately, this is a "catch-22" situation since it

> cannot be ascertained until one knows the atomic weight. Dalton assumed that if only one compound of two elements is known, it contains one atom of each element. The later tables of Dalton's…show a marked improvement in accuracy, but the values are still difficult to recognize because of these errors in valency, i.e., some equivalent weights (atomic weight/valance) are quoted rather than atomic weights. (p. 9).

Spronsen (1969) provided a look at two scientists involved in the concept of atomic weights at the same time that Dalton was doing his work. In 1808, Joseph Gay-Lussac would determine that gases form compounds with each other in simple volume ratios. This is referred to as *The Law of Combining Volumes of Gases*. In 1811, Amedeo Avogradro proposed a theory based upon Gay-Lussac's law, it suggests that all gases under the same conditions would contain the same number of molecules, and a molecule may contain more than one type of atom. It would take about fifty years to establish a molecular theory even though most of the laws were in place to make it happen. According to Spronsen (1969):

> One of the reasons for the general reluctance to combine Dalton's atomic theory with the hypothesis of Avogradro stems from the fundamental difference between the two scientists concerning the concept of chemical bonds; whereas Dalton assumed there are bonds only between dissimilar atoms, Avogradro believed bonds also existed between similar atoms. (p. 42).

Avogradro's theory would essentially be ignored for fifty years until Stanislao Cannizzaro would understand its relevance to the emerging molecular theory.

Holden (2004) told of another scientist who based his work on Gay-Lussac. Jons Jacob Berzelius is credited with developing a system of chemical notation and formulas very similar to what researchers use today. Berzelius is credited with the discovery of eight elements, and of establishing a table of atomic weights. Unlike Dalton, Berzelius atomic weights used oxygen as the reference element instead of hydrogen. He felt that oxygen would be better than hydrogen because it is was found in most compounds and unlike hydrogen; its weight could be measured directly. Spronsen (1969) explained that Berzelius did not realize the importance of Avogradro's hypothesis. He goes on to say "Berzelius made use of the correct formulas H_2O, NH_3, etc., but he made no distinction between atoms and molecules in gases such as hydrogen and oxygen." (p. 49-50). This ultimately would cause Berzelius to assume incorrectly that there were unequal particles in equal volumes of gases (opposite of Avogradro's hypothesis). Scientists like; William Prout (British), Jean Dumas (French), Jean Servais Stas (Belgium), Leopold Gmelin (German), and Charles Gerhardt (French) would contribute to the atomic weight controversy and the concept of the atom and molecule. In 1857 Friedrich August Kekule demonstrated the quadrivalence of carbon. This would help to provide some more thought about valence and further stimulate the development of horizontal relationships among the chemical elements, but it would be Stanislao Cannizzaro who would restore order to the conflict.

Emsley (1989) mentioned:

> In 1858 Cannizzaro published his '*Outline of a Course of Chemical Philosophy*' in which he showed how atomic weights could be deduced if Avogardro's Law was accepted, and he presented a paper at the First

> International Scientific Chemical Congress which was held at Karlsruhe in 1860. (p. 265).

Holden (2000) noted further that about 140 leading European chemists met the first time to reach some agreements on atoms and molecules. "Cannizzaro called attention to the value of Avogadro's distinction between atoms and molecules as an organizing device for the interpretation of chemical phenomena." (p.10). Emsley (1989) continued to explain that Cannizzaro's ideas were quickly accepted and copies of his tables of atomic weights were eagerly sought by members. One fell into the hands of a young Russian student, Dimitri Mendeleev. Spronsen (1969) indicated that Cannizzaro made the first acceptable distinction between atom and molecule and that he also found that many of Berzelius' atomic weights were correct, but his amounts for the alkali metals were twice too high because of the lack of understanding in relationship to valency.

Emsley (1989) informed us that from the time of Lavoisier to Cannizzaro the list of elements grew to over 60 in number and atomic weights had been calculated for most of them. The time period from 1800 to 1810 the chemical world saw the discovery of about one new element per year, this is a result of the understanding gained from Dalton's atomic theory and new laboratory techniques develop by Lavoisier.

Lavoisier had provided the necessary qualitative component needed for the periodic system. Cannizzaro brought the quantitative component to a standard, and numerous other scientists using Dalton's atomic theory discovered an enormous number of elements. Periodic law and the periodic system were ready for discovery.

Classification of the elements was the next major development of the periodic tables progression.

The History of the Tables Development:
Early Attempts at a Periodic System

Mazurs (1957) research credits the first attempt at a periodic system to Louis Bernard Guyton de Morveau in 1782. His table seen in Figure 1 would be reproduced five years later by Lavoisier and others when they published *Methode de Nomenclature chemiique* in 1787. The next attempt at a system was made based upon the discovery of the Law of Triads by Johann Wolfgang Dobereiner in 1817 with his final paper being published in 1829.

de Morveau Non Decomposable Substances

Simple Substances	Simple Combustible Substances	Metallic Substances	Simple Earths	Alkalies
Light Heat O H	N C S Cl B F etc.	As Fe Mo Sn W Pb Mn Cu Ni Hg Co Ag Bi Pt Sb Au Zn	SiO_2 Al_2O_3 BaO MgO	NaOH KOH NH_4OH

Figure 1. Element Systems of de Morveau (1782) and Lavoisier (1784)

Spronsen's (1969) research reflected that it is Dobereiner who should be credited with discovering a system in which all the elements could be classified according to atomic weight, and first realizing that atomic weight was an essential factor in terms of relationships between the elements. Doberiener's triad concept seen in Figure 2 was based upon H=1 and Oxygen=7.5 and his discovery shows metal oxides of calcium, barium and strontium had a unique relationship. He calculated that the average weight of the calcium oxide (27.5) and barium oxide (72.5) was equal to the average weight of strontium oxide (50), thus the concept of triads was devised. Doberiener would identify the triad relationships between several other elements and he would later realize that O=16 is the correct value and would reflect this change in his later work. For the next thirty years following the Doberiener publications only Leopold Gmelin published any further work on this concept.

Li	Mg	Ca	Be	B	P	?	S	F	Cl
Na	?	Sr	Al	Si	As	Sb	Se	?	Br
K	?	A	?	?	?	Bi	Te	?	I
Y	Zr	Fe	Ni	Ru	Pt	Ag	?	?	?
Ce	Ti	Co	Cu	Rh	Ir	Pb	Sn	Au	W
?	Sn	Mn	Zn	Pd	Os	Hg	Cd	W	Ta

Figure 2. Dobereiner System of Triads (1829)

Mazurs (1957) showed Gmelins table published in 1943, this table (Figure 3) represented the much larger group relationships of the elements based upon the original triad ideas of Doberiener. Gmelins tables were arranged downwards in order of increasing valance, the first attempts at arranging the elements using valence as the structure. The reflection of larger groups and organization of the elements according to valence groups would later be a key to the discovery of periodic law.

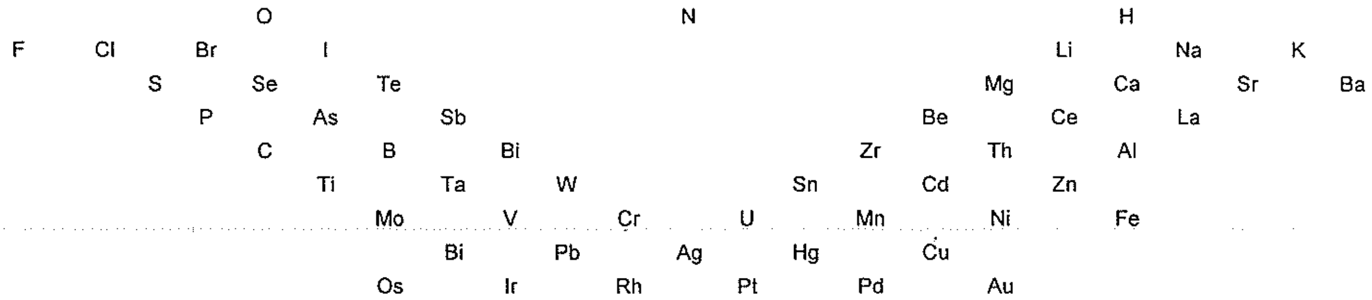


Figure 3. Gmelin System of Elements (1843)

Spronsens (1969) indicated scientists whose work investigating the concept of triads, tetrads, pentads and grouping of the elements, according to valances (1-7) provided very useful data to all the future discovers of periodic law. These scientists, in order of contribution, are Petterkofer (1950), Dumas (1951), Kremers (1852 and 1856), Gladstone (1853), Cooke (1854-1855), Lenssen (1857), Odling (1857), and Dumas (1858).

Group 1	F belongs to Cl, Br, and J
Group 2	O belongs to S, Se, and Te
Group 3	N, P, As, Sb, Bi
Group 4	B, Si, Ti, Sn
Group 5	Li, Na, K
Group 6	Ca, Sr, Ba
Group 7	Mg, Zn, Cd
Group 8	Gl, Y, Th
Group 9	Al, Zr, Ce, U
Group 10	Cr, Mn, Co, Fe, Ni, Cu
Group 11	Mo, V, W, Ta
Group 12	Hg, Pb, Ag
Group 13	Pd, Pt, Au

Figure 4. Element Groups of Odling (1857)

William Odling in 1857 was the first to arrange the elements into thirteen groups as see in Figure 4, and he was the first to show the relationship between the first four groups, this would be the first attempt at an organizational pattern that showed the relationships of elements chemical and physical properties (vertical) and valency (horizontal). Dumas published his paper in 1859 that reflected a numerical relationship between the fluorine and nitrogen groups (difference of 5) and those of magnesium and oxygen (difference of 4).

Spronsen (1969) went on to summarize these findings, "Although these relationships were limited, their observation must be considered as a turning-point in the study of connections between elements." (p. 95). These ideas (valency) along with the results of the Congress held at Karlsruhe in 1860 (atomic weight) would provide the foundation for the first attempts at a periodic law.

The History of the Tables Development:
The Periodic Law

Emsley (1989) stated that the first to attempt to compose a periodic system came from not a chemist, but a French geologist named Alexandre Emile Becuyer de Chancourtois. Chancourtois wrote down the elements in order of increasing weight (sixteen columns laid out) and then wound the paper up into a spiral form in the shape of a cylinder. Emsley stated:

> Chancourtois noted that certain triads came together down the cylinder, such as the alkali metals, lithium, sodium, and potassium whose atomic weights are 7, 23 (7+16), and 39 (23+16)…He called his model the Vis Tellurique (Telluric Screw) and published it in 1862. He concluded 'the properties of substances are the properties of numbers. (p. 265).

Chancourtois had discovered a numerical rhythm to the elements, *the periodic nature of the elements*.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
H						Li		Be		B	C		N		O
		F				Na	Mg			Al	Si			P	S
		Cl				K	Ca								Ti
				Cr		Mn	Fe			Ni	Co			Cu	
Zn		Zr								As				Br	Se
						Rb	Sr			La	Ce				Mo
		Di	Y			Tl	Rh			Pd	Ag			Cd	
		Sn				Th	U	Sb			Cs			I	Te
							Ta	W							
				Ir		Pt	Au				Hg	Ru			Os
Bi															

Figure 5. Element System of de Chancourtois (1863)

Mazurs (1957) indicated that Chancourtois table of sixteen in Figure 5 could also be laid out in multiplies and shortened to seven main groups of similar elements found in Figure 6. Chancourtois was close to a major discovery, but credit is given to John Alexander Reina Newlands and the pattern of seven called the Law of Octaves laid out in Figure 7. Newland published and announced his Law of Octaves to the London Chemical Society in 1865. Emsley (1989) pointed out that, "Newland arranged the 56 elements into groups and noted that there seemed to be a repetition of properties with every eighth element" (p. 266).

Newlands' system had a few flaws that would prove costly for him and the discovery of periodic law. Newlands' tables intentionally omitted several elements that were known at the time, he also incorrectly arranged numerous elements in his tables, and his tables did not leave free intervals for elements yet to be discovered, even though all his dated supported the idea that some missing elements where needed to complete some triads.

1	2	3	4	5	6	7
H	Li	Be	B	C	N	O
F	Na	Mg	Al	Si	P	S
Cl	K	Ca				
					As	Se
	Rb	Sr				Mo
						Te
	Au					

System of de Chancourtois (1863)

Figure 6.

1	2	3	4	5	6	7
H	Li	Be	B	C	N	O
F	Na	Mg	Al	Si	P	S
Cl	K	Ca		Ti		
	Cu	Zn			As	Se
Br	Rb	Sr		Zr		
	Ag	Cd		Sn	Sb	Te
I	Cs	Ba				
					Bi	

System of Newlands (1865)

1	2	3	4	5	6	7
H 1	**Li** 2	**Be** 3	**B** 4	**C** 5	**N** 6	**O** 7
F 8	**Na** 9	**Mg** 10	**Al** 11	**Si** 12	**P** 13	**S** 14
Cl 15	**K** 16	**Ca** 17	**Cr** 19	**Ti** 18	**Mn** 20	**Fe** 21
Co, Ni 22	**Cu** 23	**Zn** 25	**Y** 24	**In** 26	**As** 27	**Se** 28
Br 29	**Rb** 30	**Sr** 31	**Ce, La** 33	**Zr** 32	**Di, Mo** 34	**Rh, Ru** 35
Pd 36	**Ag** 37	**Cd** 38	**U** 40	**Sn** 39	**Sb** 41	**Te** 43
I 42	**Cs** 44	**Ba, V** 45	**Ta** 46	**W** 47	**Nb** 48	**Au** 49
Pt, Ir 50	**Tl** 53	**Pb** 54	**Th** 56	**Hg** 52	**Bi** 55	**Os** 51

Figure 7. Newlands Law of Octaves (1865)

Finally, Newland's greatest error came when he related his repeating patterns, law of octaves, to musical octaves. This ill-advised choice cost him credibility and prevented the London Society from publishing his paper; it was received so poorly that G.C. Foster asked him humorously if he could have arranged the elements in alphabetical order. During one of Newlands' attempts to answer his critics he stated that any further elements discovered would develop into new groups of series, this would indeed be proven true when the noble gases where discovered and the eighth row was added. It should be noted that Newlands' was eventually honored by the Royal London Society 23 years later (Spronsen, 1969).

"The Periodic Law states that the properties of the elements repeat themselves periodically with increasing atomic weight (or number). The forerunners of the Periodic Law were the three authors who unknowingly drew tables according to this Law, but did not announce the Law." (Mazurs, 1957, p. 4). William Odling was the only major discover of the periodic system that contributed to the prior preparation. As mentioned earlier Odling in 1857 was instrumental in showing the relationships between the groups, referred to as valency. Odling presented papers at the Karlsrube Congress and it would be safe to assume that many scientists thought he or Dumas would be the ones to discover the periodic system of the elements. Odling presented his 1864 table in Figure 8 that would come very close to that of Mendeleev's first chart, he was the first to leave gaps where elements were missing, he included 57 of the 60 known elements, and he arranged his table according to increasing atomic weight.

						Ro	104	Pt	197
						Ru	104	Ir	197
						Pd	106.5	Os	199
H	1	"		"		Ag	108	Au	196.5
"		"			65	Cd	112	Hg	200
L	7	"		"		"		Tl	203
G	9	"		"		"		Pb	207
B	11	Al	27.5	"		U	120	"	
C	12	Si	28	"		Sn	118	"	
N	14	P	31	As	75	Sb	122	Bi	210
O	16	S	32	Se	79.5	Te	129	"	
F	19	Cl	35.5	Br	80	I	127	"	
Na	23	K	39	Rb	85	Cs	133		
Mg	24	Ca	40	Sr	87.5	Ba	137	"	
		Ti	50	Zr	89.5	Ta	138	Th	231.5
		"		Ce	92	"	"		
		Cr	52.5	Mo	96	V	137		
		Fe	55			W	184		
		Co	56						
		Ni	59						
		Cu	63.5						

Figure 8. Element System of Odling (1864)

There were two problems with Odling's table; he was unable to explain the theoretical relationships between the elements, and several elements were placed in the wrong location. Odling continued to refine his table and he was able to correctly place some of the questionable elements, but he took retrogressive steps as well. The table he published four years later in 1868 would only include 46 of the known elements, primarily because he did not know where the other 14 fit. Secondly, he moved some elements that were correctly placed originally to an incorrect position (Spronsen, 1969).

Mazurs (1957) stated that Gustavus Detlef Hinrichs was the second forerunner to come close to periodic law. Hinrich studied and worked in astronomy and he formulated a theory that the distances between the planets in relationship to weight might be the same for the elements and their atomic weights. He used his knowledge of spectra lines (wavelengths) to formulate mathematical calculations. Hinrich published a table, referred to as natural classification, based upon his findings in 1867 and although complicated in its derivation, showed periodicity. The difficulty with Hinrich's table was that he did not publish his table with numerical values. He stated that the elements were arranged according to increasing atomic weight but other researches discovered that several were arranged in decreasing values. He misplaced several elements and failed to combine some obvious groups. Hinrich did provide the 1869 table in Figure 9 that fixed some problems and for the first time included a line to separate the metallic elements from the non-metallic elements that would become a standard on tables of today.

Pantoids	H	--------		--------		--------		--------		
Kaloids	Li	Na		Ka		Rb		--------		
Calcoids	--------	--------		Ca		Sr		Ba		
Cadmoids	(Be ?)	Mg			Zn		Cd		Pb	
Hydrargoids	--------	--------			--------		--------		Hg	
Cuproids	--------	--------			Cu		Ag		Au	
Ferroids	(Be ?)	Al			Co-Ur Ni, Fe Mn, Cr		Rh		Ir	
Molybdoids	Bo	--------					Mo		Wo	
Titanoids	C	Si			Ti		Pd		Pt	
?							Sn			
Nioboids	--------	--------			Va		Nb		Ta	
Phosphoids	N	P	P		As	As		Sb		Bi
Sulphoids	O		S			Se		Te		--------
Chloroids	Fl		Cl			Br		Io		--------
Pantoids	H		--------			--------		--------		--------

Figure 9. Natural Classification of Elements by Hinrichs (1869)

Spronsen (1969) stated "This would be Hinrichs' last publication on his system. In 1893 he reported a system of atomic weights, but only to illustrate the advantages of C=12 as the standard." (p. 124). The concept of C=12 as the standard will be addressed later in this paper. Strathern (2000) expressed that the final author before Mendeleev to submit a table was Julius Lothar Meyer. Meyer would be in attendance at the Karlsruhe Congress where he was able to review the quantitative data on the elements. Meyer published his first table in 1864, for inclusion in his chemistry textbook; this was the same purpose behind the work of Mendeleev. The table was based upon Dalton's atomic theory and Avoagradro's hypothesis. This would be Meyer's first attempt at periodic law and like the other authors stated above, it had several problems. Meyer's table was designed based upon valency as being the guide, thus using valency did not allow him to include all the elements into the table. He did establish seven groups, but unfortunately he did not work to organize the elements into increasing atomic weight. Spronsen (1969) pointed out that Meyer was reluctant to change or alter the existing atomic weights and ultimately felt that the atomic weights would show a better agreement when they eventually were determined more accurately. Meyer's table seen in Figure 10 included a free interval between silicon and tin, but Meyer did not present any predictions or make any reference to the empty space.

Spronsen (1969) pointed out: "Meyer's second system was ready in 1868, when he prepared the second edition of his textbook, which he based on the atomic theory and systematization of elements. This volume was not published until 1872." (p.127). The delay in publication has been attributed to two possible reasons. First, Meyer moved from Eberswalde to Karlsruhe in 1868 to become professor at the Polytechnic Institute which provided to be a major distraction to him.

I	II	III		V	VI	VII	VIII	IX
	B = 11.0	Al = 27.3	---	---	---	?In = 113.4	---	Tl = 202.7
	C = 11.97	Si = 28		---		Sn = 117.8	---	Pb = 206.4
			Ti = 48		Zr = 89.7			
	N = 14.01	P = 30.9		As = 74.9		Sb = 112.1		Bi = 207.5
			V = 51.2		Nb = 93.7		Ta = 182.2	
	O = 15.96	S = 31.98		Se = 78		Te = 128?		
			Cr = 52.4		Mo = 95.6		W = 183.5	
	F = 19.1	Cl = 35.38		Br = 79.75		J = 126.5		
			Mn = 54.8		Ru = 103.5		Os = 198.6	
			Fe = 55.9		Rh = 104.1		Ir = 196.7	
			Co-Ni = 58.6		Pd = 106.2		Pt = 196.7	
Li = 7.01	Na = 22.99	K = 39.04		Rb = 85.2		Cs = 132.7		
			Cu = 63.3		Ag = 107.66		Au = 196.2	
?Be = 9.3	Mg = 23.9	Ca = 39.9		Sr = 87.0		Ba = 136.8		
			Zn = 64.9		Cd = 111.6		Hg = 199.8	

Figure 10. Periodic System of Meyer (1870)

The second possibility is that he provided a copy of his manuscript to his successor at Eberswalde, Adolf Remele, for review who did not provide very fast feedback.

The delay in publishing would set into works one of the greatest battles for priority ever seen to date. Mendeleev would publish his table in 1869, after Meyer wrote his second (1868), but before it was published (1872). Meyer's second table succeeded in including all the elements in main and sub-groups and it was also arranged according to increasing atomic weights. A comparison between this table and Mendeleev's first table absolutely showed that they both had arrived at the discovery of periodic system. Mendeleev and Meyer would both miss locate some elements due to inaccurate values for some atomic weights; this would be resolved later with the discovery of isotopes and more accurate measuring tools. Strathern (2000) pointed out that Mendeleev would prevail in the long run, but it would be a battle that would see Mendeleev continued to degrade Meyer's even after Meyer's death in 1895.

A complete examination of the priority battle between Meyer and Mendeleev would take us outside the scope of this paper. The life of Dimitri Mendeleev is very well documented and appears in numerous individual books and articles and would also take us outside the scope of this paper. The author (Michael Bailey) has attempted to limit the literary review to a little history of Mendeleev's life, some of the key facts behind Mendeleev's tables, and identifying some critical differences between the Mendeleev and Meyer's tables.

Rouvray (1994) talked about Mendeleevs contribution to chemistry:

> On 17 February 1869, Mendeleyev jotted down the symbols for the chemical elements, putting them in order according to their atomic weights. He wrote down the sequence in such a way that they ended up grouped on the page according to known regularities or "periodicities" of behavior. It was perhaps the greatest breakthrough in the history of chemistry. Mendeleyev's ideas totally changed the way chemists viewed his or her discipline. Now each chemical element had its number and fixed position in the table, and from this it became possible to predict its behavior; how it would react with other elements, what kind of compounds it would form and what sort of physical properties it would have. (p. 36).

Gribbin (2002) stated Dmitri Mendeleyev was born in Siberia, on February 8, 1834. He was the youngest of fourteen children, his father died in 1847, and his mother determined that her youngest child should receive the best possible education moved them to St. Petersburg. At age sixteen he enrolled as a student teacher at the Pedagogical

Institute where he established himself as a teacher and was allowed to take a master's degree in chemistry at the University of St. Petersburg, graduating in 1856. Dmitri worked for a number of years at the University in a junior capacity, before moving on to work on a government grant in Paris and Heidelberg. It was during these excursions that he would work with Robert Bunsen and Gustav Kirchoff and gained valuable insight into chemical and physical properties of elements. He attended the Congress at Karlsruhe in 1860 at the young age of twenty-six. He returned to St. Petersburg to become a professor of general chemistry in the city's Technical Institute as he worked on his PhD. He received his doctorate degree in 1865 and in 1866 he became a professor of chemistry at the University of St. Petersburg, a very prominent position for a thirty-two year old. It was at the University of Petersburg that he realized he did not have an adequate textbook to teach his inorganic chemistry class.

Emsley (1989) pointed out:

> Mendeleyev ... began to write his textbook *The Principles of Chemistry*, ... It was while preparing the second volume that he made his momentous discovery. In trying to find a format for the chapters of the book, he grouped the elements according to valency. On a winter's day in 1869 the breakthrough happened...He wrote the name of each element on individual pieces of card, together with its atomic weight, a few physical properties and the formulae of any hydrides and oxides it formed. These cards he arranged in sets of increasing atomic weights with elements having the same valency, expressed by hydrides and oxides, in the same row. He produced one arrangement that particularly impressed him and

> wrote it down on the back of an envelope. This can be considered his first periodic table *(see Figure 11)*, and the envelope he wrote it on still exists. After his midday meal he took a nap, and on waking he decided that a vertical arrangement of groups was a better way of depicting the periodic table. This event was to give rise to the romantic notion that the periodic table came to Mendeleyev in a dream. In any case his table and this has remained the standard format to this day. (p. 269)

Strathern (2000) also mentioned the dream:

> In Mendeleyev's own words: 'I saw in a dream a table where all the elements fell into place as required. Awakening, I immediately wrote it down on a piece of paper.' In his dream, Mendeleyev had realized that when the elements were listed in order of atomic weights, their properties repeated in a series of periodic intervals. For this reason, he named his discovery the Periodic Table of the Elements. (p. 286).

Spronsen (1969) mentioned that Mendeleev wanted to do more than just put together numerical relationship between the elements; he was attempting to putt together a system of the elements. Mendeleev's attendance at the Congress in 1860 had provided him access to the elemental relationship work done by Stanislao Cannizzaro and he was also informed of the works of Kremers, Cooke, Pettenkofer, Odling's (1857 work), Dumas and Lenssen.

				Ti = 50	Zr = 90	Zr = 180
				V = 51	Nb = 94	Nb = 182
				Cr = 52	Mo = 96	Mo = 186
				Mn = 55	Rh = 104.4	Rh = 197.4
				Fe = 56	Ru = 104.4	Ru = 198
				Co = 59	Pd = 106.6	Pd = 199
H = 1			Ni =	Cu = 63.4	Ag = 108	Ag = 200
	Be = 9.4	Mg = 24		Zn = 65.2	Cd = 112	
	B = 11	Al = 27.4		? = 68	Ur = 116	Ur = 197?
	C = 12	Si = 28		? = 70	Sn = 118	
	N = 14	P = 31		As = 75	Sb = 122	Sb = 210
	O = 16	S = 32		Se = 79.4	Te = 128?	
	F = 19	Cl = 35.5		Br = 80	J = 127	
Li = 7	Na = 23	K = 39		Rb = 85.4	Cs = 133	Cs = 204
		Ca = 40		Sr = 87.6	Ba = 137	Ba = 207
		? = 45		Ce = 92		
		? Er = 56		La = 94		
		? Yt = 60		Di = 95		
		? In = 75.6		Th = 118?		

Figure 11. Periodic System of Mendeleev (1869) (Mendelejeff, D., 1869)

According to Mendeleev's own statements he was not familiar with the works done by De Chancourois, Newlands, Odling (1864 and 1868), Meyer or Hinrich.

Spronsen (1969) added:

> It should be clearly understood that Mendeleev's work was so brilliant precisely because he know nothing of studies of his contemporaries which had been published on the same subject since 1862. If he had known them, Mendeleev's work could only be considered as a useful summary and continuation of that of his predecessors. It should be noted that, in those days, because of poor communication and publication facilities, the scientific responsibility of an author was not yet taken to include thorough literature searches. (p. 135).

This would be a major point when priority was questioned by Meyer and Dumas.

Meyer's original table was based upon valency as were several other earlier attempts by others. Dmitri Mendleev table was based upon both atomic weight and valency and this would be called The Periodic Law and it would be explained to the Russian Chemical Society in March of 1969, two weeks after Mendeleev would discover the Law, it was read by N.A. Menshutkin because Dmitir was ill (Mazur, 1957).

Mendeleev's table broke with traditional methods that incorporated only one or two analogous properties; his table would draw upon all the available chemical knowledge. He separated elements that he felt needed to be in different locations, even if this meant it did not match an individual analogous property. He was to boldly state that the atomic weights of some elements were incorrectly determined and he placed these elements into the location he felt was a better location on his table, based upon chemical and physical properties instead of atomic weight. Example: Tellurium was considered to be 128 and thus should be after Iodine; Mendeleev felt it was closer to 124 or 126 and put it before Iodine, based upon its properties. This would eventually prove to be a wrong prediction for Mendeleev, but not until the discovery of isotopes forty years later. Besides the tellurium-iodine problem there was also the cobalt-nickel problem where Mendeleev was the first to place cobalt and nickel in the system in the correct order. Mendeleev's table was not without errors and he made statements that indicated that he was not comfortable with the placement of certain elements, referred to as the rare earths, these he placed at the bottom of his third and fourth periods (Er, Yt, In, La, Di, Th) (Strathern, 2000).

What eventually would solidify Mendeleev's tables as being superior to all others can be attributed to a group of special elements. These elements did not exist at the time that Mendeleev would arrange his cards, these are the elements that Mendeleev predicted would be found. The strength in his table was in the idea that a complete table would not only allow the user see patterns of periodicity, but to predict patterns of chemical behavior. Mendeleev would predict ten different elements and eventually seven of them would be found. Of the ten elements, it would be the discovery of three of them that would propel his tables into history. Figure 12 shows his predictions and the eventual discoveries; it would be gallium, discovered by Paul-Emile Lecoq de Boisbaudran in 1875, that would have scientists around the world beginning to understand the strength of Mendeleev's table.

Spronsen (1969) noted:

> Mendeleev supported his statement that the usefulness of a system increases with the number of its applications, by recapitualating a few of them. The system can be applied:
>
> 1) as a classification of elements;
> 2) to determine the atomic weights of elements not sufficiently analyzed;
> 3) to examine properties of unknown compounds;
> 4) to correct erroneously determined atomic weights; and
> 5) to collect information about the properties of compounds.
>
> Mendeleev could indeed make all these applications; in this respect his system is superior to the others. (p. 138).

Over the next two years, and up until his death, Mendeleev would produce several different styles of tables and he would continue to refine his tables by making minor adjustments to some elements as more exact information was determined.

Mendeleev Predictions		Determination
Eka-aluminum		Gallium
		(Discovered in 1875 by de Boisbaudran)
Atomic Weight	68	69.9
Density	6	5.96
Atomic Volume	11.5	11.7
Eka-boron		Scandium
		(discovered in 1879 by Nilson)
Atomic Weight	44	43.79
Density	3.5	3.864
Oxide	Eb_2O_3	Sc_2O_3
Sulphate	$Eb_2(SO_4)_3$	$Sc(SO_4)_3$
Eka-silicon		Germanium
		(discovered in 1886 by Winkler)
Atomic Weight	72	72.3
Density	5.5	5.469
Atomic Volume	13	13.2
Oxide	EsO_2	GeO_2

Figure 12. Predication of elements by Mendeleev (1871)

He would draw up tables that would provide the makings of the periodic table that we are most familiar with today. Figure 13 was produced by Mendeleev in 1871 and it reflects the element groups based upon valency forms, oxides and hydrides that would identify the vertical relationships and follows the horizontal property of atomic weight. Mendeleev would also produce the table in Figure 14 that he considered to be not very convenient. Interestingly, it would be this table that winds up as the beginning point of the current, very popular table used today.

REIHEN	Gruppe I - R^2O	Gruppe II - RO	Gruppe III - R^2O^3	Gruppe IV RH^4 RO^2	Gruppe V RH^3 R^2O^5	Gruppe VI RH^2 RO^3	Gruppe VII RH R^2O^7	Gruppe VIII - RO^4
1	H=1							
2	Li=7	Be=9.4	B = 11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	- = 44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59 Ni=59, Cu=63
5	(Cu=63)	Zn=65	- =68	- =72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	- =100	Ru=104, Rh=104 Pd=106, Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	-	-	-	
9	-	-	-	-	-	-	-	- - - -
10	-	-	?Er=178	?La=180	Ta=182	W=184	-	Os=195, Ir=197 Pt=198, Au=199
11	(Au=199)	Hg=200	Ti=204	Pb=207	Bi=208	-	-	
12	-	-	-	Th=231	-	U=240	-	- - - -

Figure 13. System of Mendeleev with Oxides and Hydrides (1871)

										Be	B	C	N	O	F
Na										Mg	Al	Si	P	S	Cl
K	Ca	-	Ti	V	Cr	Mn	Fe	Ni,Co	Cu	Zn	-	-	As	Se	Br
Rb	Sr	-	Zr	Nb	Mo	Rh	Ru	Pd	Ag	Cd	U	Sn	Sb	Te	I
Cs	Ba	-	-	Ta	W	Pt	Ir	Os	Hg	-	Au	-	Bi	-	-
Tl	Pb	-													

Figure 14. Alternate Table of Mendeleev (1871)

The next section of this paper will look at the changes that have molded the table from Mendeleev 1971 publication until the present form.

Glenn T. Seaborg (1996) summarized these changes:

> As time progressed, adjustments had to be made to the Periodic Table to accommodate the rapidly expanding knowledge of the properties of the elements and their atomic and nuclear structures. Also, additional elements were discovered during the late 19th century and the first part of

> the 20th century which required some reconstruction of the Mendeleev periodic system. The most significant changes were the addition of another vertical row, or group, of elements now known as the noble gases, and the substitution of a series of elements, the rare earths or lanthanides, in the place of a single element (placed between barium and hafnium). (p. 2999).

Major Changes to the Table:
The Noble Gases

Emsley (1989) mentioned that it would be the research of Lord Rayleigh's that would begin the isolation of a new group of elements. Rayleigh calculated a difference between the density of nitrogen from air (1.257) and from the decomposition of ammonia (1.251). Rayleigh along with William Ramsay investigated the difference and concluded that the one percent difference was in fact another element an inert gas they would call argon (this gas was first discovered over a hundred years earlier in 1766 by Henry Cavendish but did he not recognize it). Ramsey would now begin to use his knowledge of the periodic system, like Mendeleev did, to predict that this new gas (element) was not alone, but that it must belong to a group. Three months later Ramsay's along with help of Morris Travers would identify an inert gas left over from the combustion of uranium ore. They would conclude that this gas was the same gas identified by Pierre Janssen and Norman Lockyer about thirty years earlier. Emsley (1989) mentioned, "In 1868 they detected it in the spectrum of light from the sun. They called the new element helium (from the Greek work helios), but it was generally assumed that it would not be found on Earth." (p. 274).

Spronsen (1969) added, “From the very beginning, Ramsay himself assumed that this gas, together with argon, had to be classified within a new group of the periodic system between the halogens and the alkali metals.” (p. 247). Having measured the atomic weight of helium (4) and argon (40), Ramsey concluded that in order to fit the pattern of the periodic system there had to be another element between these two (atomic weight ≈ 20). He also concluded that they would find two more elements between bromine (80) and rubidium (85), and between iodine (127) and caesium (133). Ramsey and Travers, concluded that they would find those elements in the atmosphere along with argon. Emsley (1989) reflected:

> By 1899 they had extracted the missing three gases: neon (atomic weight 20), krypton (84), xenon (131), naming them after the Greek words *neon* (new), *kryptos* (hidden), and *xenos* (stranger). The heaviest member of the group is radioactive radon…discovered… in 1900 by F.E. Dorn at Halle in Germany. (p. 274).

Mendeleev would live to see the addition of this new group of elements to his system; these would have a valency of zero and would follow the periodic pattern of atomic weight, except for argon whose weight was calculated to fall between potassium and calcium. Similar to how Mendeleev had done on his system; Ramsey chose to place argon according to it properties instead of its atomic weight, thus placing it below neon and above krypton. Eventually this dilemma would work itself out with the discovery of isotope forms a few years later.

Major Changes to the Table:
The Rare Earths

Spronsen's (1969) research pointed out that the placement of the rare earths into the periodic system would prove to be very difficult for the early discoverers. In 1871 there were only four known rare earth elements (lanthanum, cerium, didymium and yttrium) and because their properties were so similar, classification was very difficult. De Chancourtois, Odling, Newlands, Meyer, and Mendeleev all had struggled with placement of these elements. In Mendeleev's table (*Figure 11, pg. 35*) these elements were placed at the end of his third period. This was Mendeleev's attempt at classifying these special elements but he would never be happy with any placement and continued to work extensively on them for the rest of his life, as did Meyer. Mendeleev and Meyer both continued to contribute useful technical information on these elements in the years following the discovery of periodic law up, until their deaths. Over the next twenty plus years more rare earth elements were being discovered and numerous attempts were made to classify these elements into the table as homologues with the other elements, but to no avail.

It would be Thomas Bayley in 1882 that would be the first to be convinced that these special elements should not be treated as homologues of other elements. Bayley's system would classify them, but he did not form a separate series. Henry Bassett in 1892 would be the first to classify the elements as a special individual group. In Bassett's table, (Figure 15) he placed ten of the twelve known rare earth elements and he would predict spaces for six others for a total of eighteen.

								Cs	133		226?
								Ba	137		?
								La	138.2		?
								Ce	140.2	Th	232.6
								Ndy	140.8		?
								Pdy	143.6	U	239.6
									148?		241?
								Sm	150		?
									?		?
									?		?
									154		248?
									?		?
								Tb	159.5		?
								Ho	162		?
									?		?
								Er	166.3		?
									169?		263?
								Tm	170.4		
									?		
								Yb	173		
				K	39.1	Rb	85.5		174?		
				Ca	40	Sr	87.6		?		
				Sc	44	Y	89.1		?		
				Ti	48	Zr	90.6		?		
				V	51.4	Nb	94	Ta	182.6		
				Cr	52.1	Mo	96	W	184		
				Mn	55		100?		189?		
				Fe	56	Ru	101.6	Os	191.7		
				Ni	58.7	Rh	103.5	Ir	193.1		
				Co	59	Pd	106.6	Pt	195		
Li	7	Na	23	Cu	63.4	Ag	107.9	Au	197.3		
Be	9	Mg	24.3	Zn	65.3	Cd	112	Hg	200		
B	11	Al	27	Ga	69	In	113.7	Tl	204.7		
C	12	Si	28.4	Ge	72.3	Sn	119	Pb	207		
N	14	P	31	As	75	Sb	120	Bi	208.9		
O	16	Si	32.1	Se	79	Te	125		?		
F	19	Cl	35.5	Br	80	In	126.9		216?		

Figure 15. Element System of Bassett (1892)

Hans Peter Jorgen Thomsen would publish his table seen in Figure 16 three years later, that would also individualize the rare earths, but unlike Bassett he predicted there would be only fourteen (which is the current value). Thomsen would make a mistake of basing his system upon only one homologue as the rest of the periodic system was based upon at least two (atomic weight and valance), thus his system fell short of ideal.

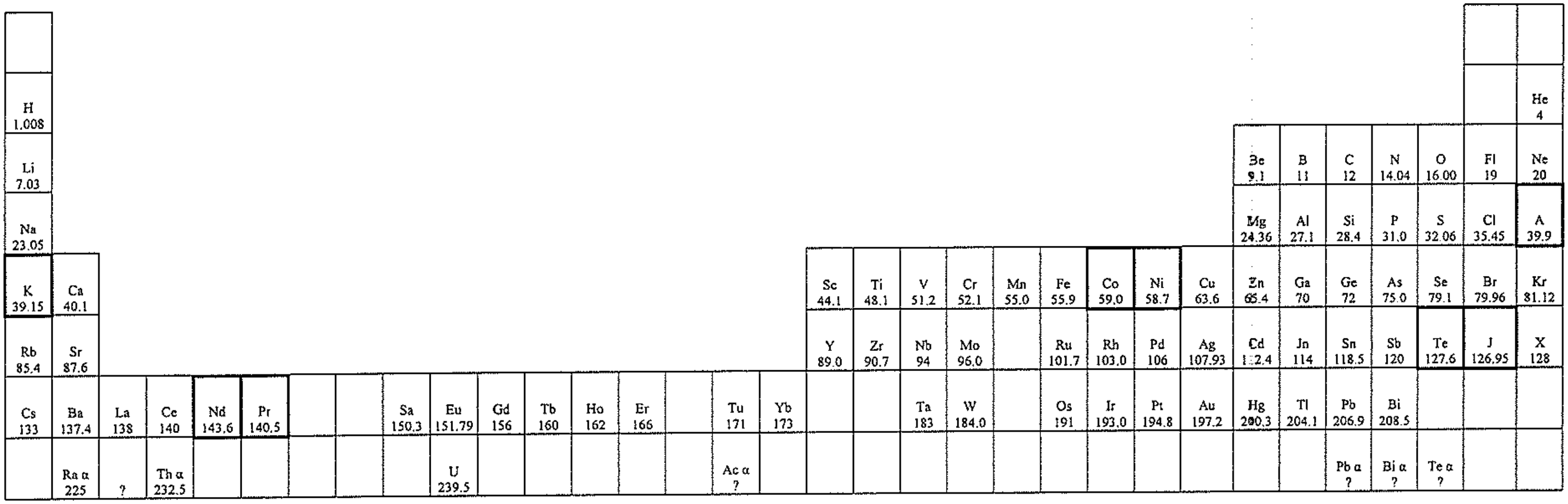
												Cs	133
												Ba	137
												La	138
												Ce	140
												Ne	141
												Pr	144
												-	-
							K	39	. .	85	Rb	Sm	150
							Ca	40	. .	87	Sr	-	-
							Sc	44	. .	89	Y	Gd	156
							Ti	48	. .	91	Zr	Trb	160
							V	51	. .	94	Nb	-	-
		Li	7	. .	23	Na	Cr	52	. .	96	Mo	Er	166
		Be	9	. .	24	Mg	Mn	55	. .			-	-
		B	11	. .	27	Al	Fe	56	. .	102	Ru	Thu	171
H	1	C	12	. .	28	Si	Co	59	. .	103	Rh	Yb	173
		N	14	. .	31	P	Ni	59	. .	107	Pd	-	-
		O	16	. .	32	S	Cu	63	. .	108	Ag	-	-
		F	19	. .	35.5	Cl	Zn	65	. .	112	Cd	Ta	183
							Ga	69	. .	114	In	W	184
							Gr	72	. .	119	Sn	-	-
							As	75	. .	120	Sb	Os	191
							Se	79	. .	125	Te	Ir	193
							Br	80	. .	127	J	Pt	195
												Au	197
												Hg	200
												Tl	204
												Pb	207
												Bi	209
												-	-
												-	-

Figure 16. Element System of Thomsen (1895)

Systems by B. Brauner, Crookes, and T. W. Preyer would all include the rare earths as an individual group and they would have differences in the arrangement of the elements. Within these arrangements researchers would find another atomic weight problem similar to the Te-I, and Co-Ni of Mendeleev, and the Ar-K pair of Ramsey.

Neodymium-praseodymium pair would have to be place out of order of atomic weight in order to give precedence to properties.

Alfred Werner published his system, Figure 17, in 1905 which would closely resemble the most popular table of today; this table would come very close to what could be called the ideal table. His table reflects the individual group of rare earth elements, spaces for undiscovered ones, and he would also attempt to classify newly discovered isotopes of La, Bi, Pb, and Te (these eventually would be removed as a better understanding of isotopes is developed). Werner's table would also highlight the four element pairs that would take opposite positions according to atomic weight (Ar-K, Co-Ni, Nd-Pr, and Te-I). This table would have some errors that would prevent it from being perfect; the perfect table would eventually be based upon the electronic configuration discovered several years later. Werner misplaced uranium and actinium which were classified as a second group of rare earth metals along with correctly placed thorium. He also classified lanthanum as a rare earth metal thus making the total rare earth elements equal fifteen and leaving a vacant space below yttrium (the debate as to what element begins the rare earth series is still apparent in the tables used today, 2004) (Spronsen, 1969).



Mendeleev's table would make it into the 20th century with only minor changes in its structure to support the discovery of the newest elements, the noble gases and the rare earths. The greatest challenges to the table validity will be with the discovery of atomic structure. The next section will investigate how the table changed to meet the new discoveries into the structure of the atom.

Major Changes to the Table:
The Discovery of Atomic Structure

The history behind the complete discovery of atomic structure would take us beyond the scope of this paper. The author (Michael A. Bailey) will limit its history to a very quick overview to give the reader enough background to begin to understand the effects these discoveries had on the periodic system.

Timmreck (1991) stated:

> In 1871, Dimitry Mendeleyev organized atoms by increasing atomic mass and periodicity of behavior-that is, repeating patterns of behavior. Whenever he found a conflict, he believed behavior and doubted atomic mass…in his time, it showed the basic pattern of order of atomic properties and chemical and physical behavior. It gave little insight into whatever architecture underlay that order. It shed no light on the behavioral variations available to some atoms and not others. Understanding the order he discovered required more knowledge. (p. 7).

Timmreck (1991) explained that Dalton's model of the atom consisted of an indivisible homogeneous ball. The middle part of the 19th century was marked by the discovery of electrons (negative particles) in a sealed glass tube called a CRT (cathode ray tube). This discovery would change the view of the atom, and start a journey that would still be going into the 21st century. Eugen Goldstein in 1885, using a CRT, was the first to see different particles in the tube traveling in an opposite direction of the electrons. He deduced that these particles must be positive in nature to counter the effects of the negative electrons; these particles would eventually be called protons. From this information J.J. Thompson would propose a new model of the atom called the "plum pudding" model. Timmreck (1991) noted, "It portrayed a positively charged protonic sphere, throughout which negatively charged electrons were somehow dispersed." (p. 17). In 1911, Ernest Rutherford shot alpha particles (two protons and two neutrons stuck together) at a thin piece of gold foil and to his surprise some of these alpha particles bounced straight back reflecting that something was drastically wrong with the "plum pudding" model of the atom. Rutherford calculated that the only way that this was possible is if there was a very dense object in the atom, he theorized that the protons must be located in the center of the atom; densely packet, and accounting for nearly all the mass of the atom; the nucleus was discovered. He went on further to deduce that the electrons must be traveling around the nucleus at high speeds and occupying the vast area around the nucleus; in essences concluding, that the atom is mostly empty space with a solid protonic core.

At about the same time the prior work was being done another experiment with the cathode ray tube would led to crucial theories about atomic structure. Different gases were placed into the CRT's and the electrons that were being shot out of the cathode hit these gases causing the tube to glow different colors. When this light was examined through a prism various line spectra were discovered. J.J. Balmer and J.R. Rydberg in

1885 studied the lines given off by the hydrogen atom and examined relationships in terms of frequencies and multiple progressive steps, these steps were given values using the variable of *n*. Max Plank in 1900 provided the relationship between these steps and a specific amount of energy (packets) associated with jumping between them, this specific energy was referred to as quantum and this was the birth of the quantum theory.

Spronsen (1969) stated "The year 1913 was one of the most important in the history of the periodic system." (p. 310). Henri Gwyn Jeffreys Moseley (1887-1915) would publish his paper *The High Frequency of Spectra of the Elements* and Neil Bohr would make a new proposal that would redefine the atomic model, both of these would occur in 1913.

Moseley (1913) stated that by examining the X-ray spectra emitted by the elements when they were excited could conclusively identify the elements according to the central positively charged nucleus. Considering that the charge carried by the nucleus is in all cases an integral multiple of the charge on the hydrogen nucleus it is possible to build the table in even increments from hydrogen being a value equal to 1. This value would be referred to as the atomic number (the variable Z is used for atomic number) and instead of arranging the elements according to atomic weight they could be arranged according to atomic number. Spronsen (1969) pointed out that this would solve the problem between the four pair of elements researchers discussed earlier (Ar-K, Co-Ni, Nd-Pr, and Te-I). These elements were out of place in terms of atomic weight sequence but they were placed according to behavior, that behavior is a result of the protons and electrons in their atomic structure; this was solidified by the X-ray spectrums that Moseley generated, the problem was solved and the elements were indeed already placed in the right positions by Mendeleev and Ramsey. It was determined that a neutral atom would contain one more proton and one more electron than the element before it on the table. The next thing that needed to be done to was to figure out how the electrons were arranged in the atom.

Timmreck (1991) stated that Neils Bohr would propose an atomic model that year (1913) that would envision the spheres having a densely packet center called the nucleus and electrons flying around at great speeds orbiting the nuclei like the planets orbit the sun. These orbits would be related to the steps and energy calculated by Max Plank. Bohr would mathematically calculate the energy related to these orbits and call these regions electron shells. These shells were given values of $n = 1$ to $n = \infty$ with $n = 1$ being the closest region to the nucleus, as the electrons bounced between these levels various amount of energy was absorbed or emitted (in the form of light), thus referred to as quantum leaps. Bohr model would be very short lived as it would fail to explain behavior of atoms other than hydrogen which is what all the calculation were based upon. Bohr's model also tried to develop a theory for electron structure that calculated the precise electron location and momentum. It would Werner Heisenberg who would explain that it is impossible to identify both components of the electron at the same time; this would be called the *Heisenberg uncertainty principle.* Bohr's idea of the energy shells would be passed along to the new atomic theory. Mazur (1959) showed that Bohr would contribute an almost ideal form of the periodic table in 1922 as seen in Figure 18. This table would incorporate Moseley's atomic numbers for the first time, list all the known elements (87 total), place the elements into seven different rows, list the rare earths as a separate row of 14, and finally correctly place Ac, Th, Pa, and U in the final row. Seaborg (2001) mentioned that Bohr would contribute a vast amount to the understanding of the elements and atomic structure, and he made significant changes to the periodic system. His contributions would be glorified by the eventual naming of element 107 after him, Bohrium.

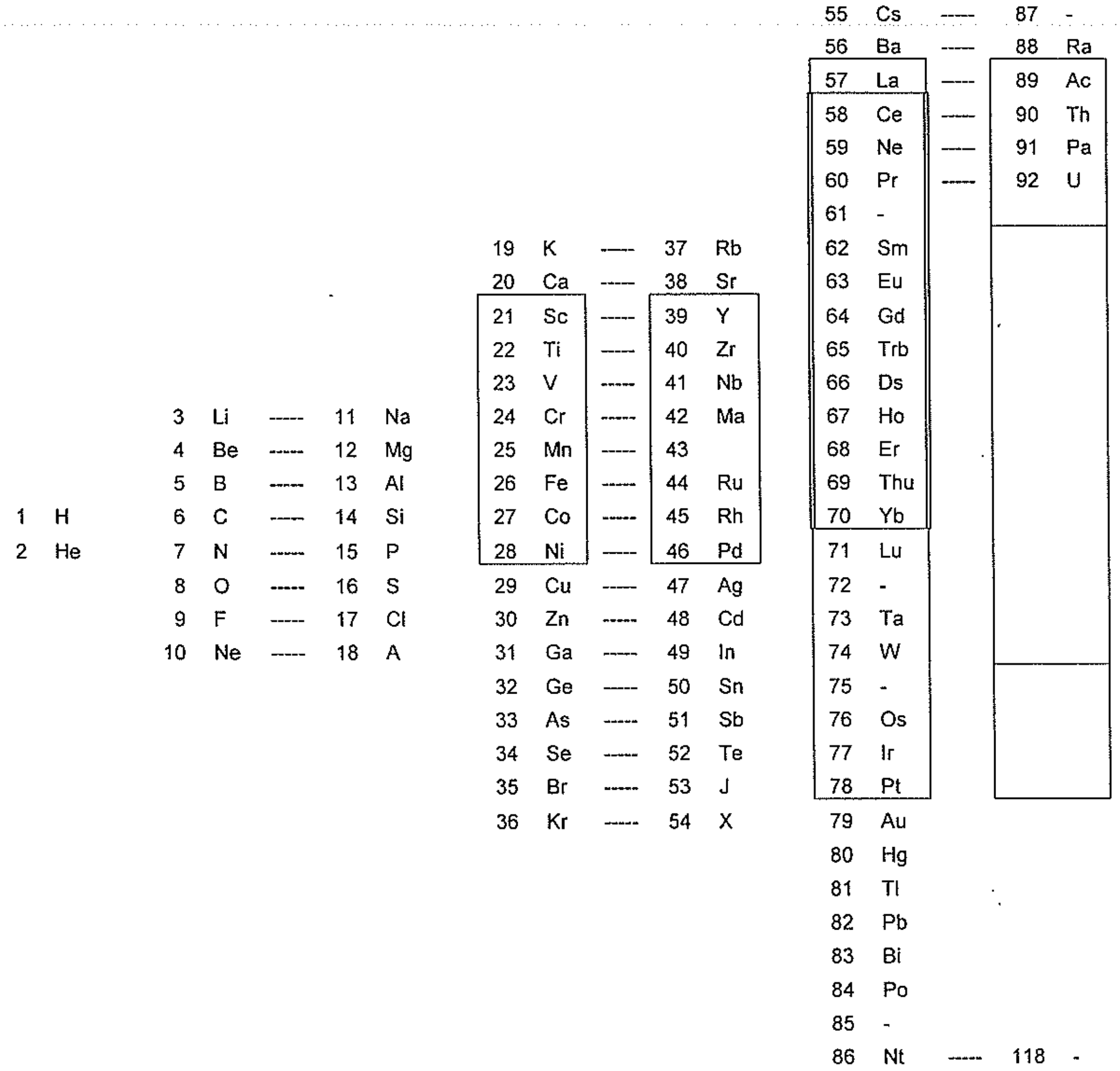


Figure 18. Element System of Bohr (1922)

According to Timmreck (1991) Erwin Schrödinger in 1926 would produce a wave equation for the electron that would define a model for the electronic structure of the atom that would do everything that the Bohr model would do, as well as everything it could not. Schrödinger's wave equation is the architecture of the atom in use today and it his equation that would help explain the behavior of elements in terms of atomic structure. His equation identified three of four quantum variables (n, ℓ, m_ℓ and m_s) used to give a vision of the atomic structure. Only the first two variables will affect the organization of the table but all four of them will help us to understand the behavior of elements. The first quantum variable n, called the principal quantum number, identifies the number of shells that the atom has starting from the nucleus of the atom. The smallest atoms would have electrons in only the first shell ($n = 1$) whereas the largest atoms in the periodic system would have electrons located in all the shells ($n = 1$ to $n = 7$). The number of electrons in each shell is defined by the equation n^2 x 2. The second quantum number ℓ, called the angular momentum quantum number, identifies the different possible areas (orbitals) within each shell. The larger the shell (from $n = 1$ to $n = 7$) the greater the possible number of areas you will have. These areas are associated with the values *s*, *p*, *d*, *f*, and etc. and correspond to 2, 6, 10, and 14 electrons, respectfully as represented in Figure 19.

Shell Number n	Possible Electrons per shell (max) (n^2 x 2)	Orbitials per shell ℓ
1	2	*s*
2	8	*s, p*
3	18	*s, p, d*
4	32	*s, p, d, f*
5	50	*s, p, d, f, g*
6	72	*s, p, d, f, g, h*
7	98	*s, p, d, f, g, h, i*

$s = 2$
$p = 6$
$d = 10$
$f = 14$
$g = 18$
$h = 22$
$i = 26$

Total Electrons per shell by orbitials
2
2+6 = 8
2+6+10 = 18
2+6+10+14 = 32
2+6+10+14+18 = 50
2+6+10+14+18+22 = 72
2+6+10+14+18+22+26 = 98

Figure 19. Quantum Numbers and Orbitals

The third quantum variable is m_ℓ, called the magnetic moment quantum number, this is used to differentiates the orbitials orientation in three-dimensional space. Lastly, the fourth quantum variable is m_s, called the magnetic spin; this one does not come from Schrödinger but is used to indicate the direction of spin on the electron.

It was determined in the early part of the 20th Century that the highest possible positive and negative valence was 8 (called the octet rule – law of octaves plus the noble gases). Using the concept of octet with the new atomic theory calculations it was determined that a period of eight elements was the preferred arrangement. Spronsen (1969) stated, "The true periods of eight elements contain atoms whose outermost shell possesses only either *s*-electrons or *s*- and *p*-electrons. The last element with 2*s* and 6*p* electrons in its outermost shell, i.e., with a complete *s*-level and a complete *p*-level, is always a noble gas." (p. 294).

Spronsen (1969) mentioned that ultimately it would be the electrons located in the outermost shell of each atom that would explain its behavior, these electrons would account for all the physical and chemical properties that Mendeleev had originally based his table upon. The elements located in the *s* columns plus the elements located in the *p* columns would add electrons to the outermost shell, where as the elements located in the middle of table would add electrons to inner shells. This would help to explain why the transition elements (*d* block groups of 10) and the rare earth elements (*f* block groups of 14) were so hard to differentiate, in principle; it was because they all had a similar number of elements in their outer shells. Hydrogen, lithium, sodium, potassium, rubidium, and cesium all behaved in a similar fashion because they all have one electron in the outmost shell, this similar conviction would explain the similar behavior for all the element groups of the periodic system; the noble gases would all be noble because they have eight electrons in the outermost shell (the one exception to this is helium with only two). The periodic system could now be grouped according to electronic behavior of the atoms (electronic configuration), visually it could be grouped according to the second quantum values of *s*, *p*, *d*, *f*. Viatschelaw Iljitsch Romanoff would publish his table in 1934, seen in Figure 20, which reflected the division of the main and sub-group elements using this concept. "Romanoff made a division after the fragments of the second and third groups' Be-Mg and Sc-Y, whereas Werner *(Figure 17, pg. 46)* made it after Li-Na and Ca-Sr in order to indicate the elements of the main group in the 4th and following periods." (p. 155-156*)*. There were numerous other scientists that would produce tables based upon this structure, but this table shows us the pattern most commonly in use.

The power behind the periodic table, with in corporation of the new atomic theory, allows anybody to build the electronic structure of the atom from the smallest element to largest element (hydrogen to those elements yet to be discovered or synthesized).

Emsley (1989) pointed out the key to the survival of Mendeleev's table:

> Mendeleyev based his table on the two properties, atomic weight and valency, which closely mirror atomic number and electron configurations. Others came close to making the same discovery, but perhaps what distinguishes Mendeleyev was his ability to grasp that the known elements fitted into a scheme that was predetermined. The elements were not being

Groups Period	1	2	3'	3'a	3'b	3'c	3'd	3'e	3'f	3'g	3'h	3'i	3'j	3'k	3'l	3'm	3'n	4'	5'	6'	7'	8'	9'	10'	1'	2'	3	4	5	6	7	0
I	1 H																															2 He
II	3 Li	4 Be																									5 B	6 C	7 N	8 O	9 F	10 Ne
III	11 Na	12 Mg																									13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
IV	19 K	20 Ca	21 Sc															22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
V	37 Rb	38 Sr	39 Y															40 Zr	41 Nb	42 Mo	43 Ma	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
VI	55 Cs	56 Ba	57 La	58 Ce	59 Pr	60 Nd	61 H	62 Sa	63 Eu	64 Ga	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb	71 Lu	72 Ct	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi Au	84 Po	85 Ab	86 Nt
VII	87 Vi	88 Ra	89 Ac	90 Th	91 Pa	92 U																										

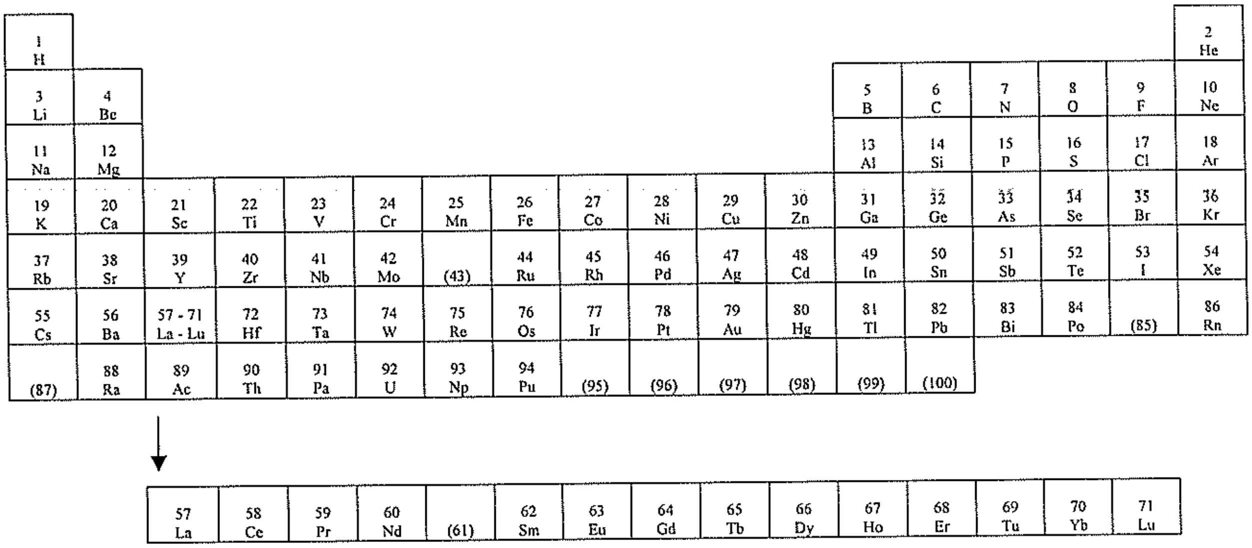
1	2
1 *s*	

(4) 3'a	3'b	3'c	3'd	3'e	3'f	3'g	3'h	3'i	3'j	3'k	3'l	3'm	3'n 3'	4'	5'	6'	7'	8'	9'	10'	1'	2'	3	4	5	6	7	0
4 *f*													3 *d*										2 *p*					

Figure 20. Element System of Romanoff (1934)

> arranged to make a periodic table, but to *fit* the periodic table. The difference may seem trivial to us today, but for its time the mental jump was truly of genius. (p. 270).

Mazur (1957) stated that even though there have been over 700 different types of periodic table all of them are based upon the same two principles of periodicity; valency and electron configuration. Mazur mentioned that the reason why researchers have adopted the periodic table used most in the United States classrooms has as much to do with science as with business. Several companies used the periodic table as a marketing tool starting in the mid-30's distributed them for free to schools and universities (this is a practice that is still prevalent today). The easiest table to reproduce was also the most practical to use and by cutting out the inner-transition elements (rare earths) and placing them on the bottom it very easy to get onto one piece of paper. Figure 21 was the common table used in the U.S. at the beginning of WWII, it was also the table used by Glenn T. Seaborg, Joseph W. Kennedy, and Arthur C. Wahl at the University of California, Berkeley in the spring of 1940. The next section will briefly discuss isotopes and how their discovery would fuel the research performed at the University of California, Berkeley.



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	(43)	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 - 71 La - Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	(85)	86 Rn
(87)	88 Ra	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	(95)	(96)	(97)	(98)	(99)	(100)				
		57 La	58 Ce	59 Pr	60 Nd	(61)	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb	71 Lu	

Figure 21. Pre-World War II Periodic System Used In USA (1939)

Major Changes to the Table:
Isotopes

Theodore W. Richards was investigating the atomic weight of lead in 1914 and discovered something very troubling. The weight of lead varied from location to location from which it was mined. This difference was very slight, but it was enough to make it a concern; one of the key components to the periodic table was atomic weight and this into question the validity of the periodic table (Emsley, 1998).

Parrington, J.R., et al (1996) found that a mass spectrograph, designed by Fracis W. Aston, would stripped atoms of electrons, giving them a positive charge, these positive particles were called *ions* from the Greek word traveler. These positive ions were forced through a series of magnetic and electrical plates that would cause them to deflect, and the heavy ions would deflect less than the lighter ones, thus allowing them to be separated.

Parrington, J.R., et al (1996) mentioned:

> With the use of mass spectrograph, it was discovered that some chemical elements have two or more components, each with its own mass. Natural chlorine, whose atomic weight is fractional (about 35.5), produced two lines on the photographic plate corresponding to masses very close to 35 and 37. No particle was found with a fractional mass. (p. 3).

The word isotope was coined by Frederick Soddy to represent components of the same chemical element with a different mass number. Chlorine's two natural occurring isotopes are Cl-35 and Cl-37.

Emsley (1998) stated that "the periodic table persisted, and the reason was that the chemical behavior of lead was not affected by its atomic weight. We now know that atoms of the same element can vary in weight because of different isotopes…"(p. 271). This would also mark a final solution to the four element pairs, Ar-K, Co-Ni, Nd-Pr, and Te-I, and explain the discrepancy in their atomic weights. Frederick Soddy would win the Nobel Prize for his work on the Tellurium-Iodine problem. Soddy determined that tellurium has eight different isotopes and two of them Te-129 and Te-130 make up 64% of the total mass of tellurium; whereas iodine has only one isotope I-127. "It is not surprising, therefore, that the atomic weight of tellurium should be higher than that of iodine."(p. 271). With the discovery of neutrons by James Chadwick in 1932 it was determined that the difference between isotopes was the number of neutrons in the nucleus of the atoms; Cl-35 has two less neutrons than Cl-37. It is the protons and electrons that determined the majority of chemical behavior so it is not surprising that different isotopes will have only a slightly different behavior from each other. The next section will look at the slight behavior difference between uranium-235 and uranium-238 and how these two isotopes would change the world we live in and the periodic table in use today.

Major Changes to the Table:
The Transactinide Series

Seaborg (1996) mentioned that there were only four missing elements (43, 61, 85, and 87) from the periodic table below Uranium (92) by the late 1930's. These four elements were considered to be radioactive, based upon nuclear properties, and would have very short half-lives making their existence on earth highly unlikely.

Seaborg (1996) stated:

> The three heaviest elements, thorium, protactinium, and uranium, were believed to be related to hafnium, tantalum, and tungsten, respectively. The next element, number 93, was thus expected to have chemical properties resembling those of rhenium. Similarly, elements 94 to 100 were expected to fit neatly into the Periodic Table. (p. 2999)

It was understood that the elements beyond uranium would not exist on the earth, but could they be made was the question addressed in the 1930's.

In Italy in 1934 Erico Fermi made the first attempts to produce new elements beyond uranium. The process is quite simple in theory, uranium atoms are bombard with fast moving neutrons. If the neutrons stick to the nucleus of the uranium atom it would under go transmutation into a proton due to the unstable nuclear structure thus changing uranium, element 92, to a heretofore unknown element 93. After the collision Fermi and other examined all the particles left over (radioactive tracers) they discovered several interesting particles. These particles were examined and Fermi concluded that they were not elements around uranium (90, 88 or 89), so he deduced the newly synthesized material must be element 93.

Seaborg (2001) wrote:

> I recall only one paper that challenged Fermi's conclusions, written by the German chemist Ida Noddack. Noddack suggested that it wasn't enough to separate the element from its neighbors on the periodic table. Before claiming he'd found a new element, Fermi should separate it from all the other elements on the periodic table. She was technically right, but as a practical matter no one thought it was necessary to do this. Noddack suggested Fermi needed to check if his element 93 was a much lighter element, for the uranium might have split in two-and no one could take that suggestion seriously. Scientists all knew it was impossible for uranium atoms to break apart in such a manner. The largest pieces that had ever been split off from a nucleus were alpha particles, which were the size of helium nucleus (two protons and two neutrons); knocking them loose required great energy. If you hit a car-size boulder with a pick, you may chip off a piece, but you won't split the boulder into two halves. (p. 56).

Otto Hahn, Lise Meitner, and Fritz Stassmann would repeat Fermi's experiment and in 1938 they proved that Fermi's work was incorrect and that Noddack's suggestion was correct. They revealed that the products were indeed isotopes of lighter elements and as a result they had split the atom. Glenn Seaborg and others were working at the Radiation Laboratory (Rad lab) at University of California when this discovery was made; they were bombarding uranium atoms with neutrons as well. Seaborg was excited about the news, but also disappointed that he missed a chance for an astounding discovery because they did not consider this to be a possibility. This would be the time that Einstein's equation $E = mc^2$ would explain the magnitude of the situation. It would be calculated that the amount of energy released during the splitting process would be huge; a kilogram of uranium-235 would contain as much energy as 3,000 tons of coal. If this could be released at once you would have an explosion like never seen before, you would have a nuclear explosion. The concern at this point in time was that with the onset of World War II. It was felt that Germany was working on developing the nuclear bomb so further research on nuclear fission became all the frenzy.

Seaborg (2001) mentioned a problem using uranium as a fission source, "Uranium occurs in two main natural isotopes, U-238 and U-235. U-235 makes up less than 1 percent of the uranium in a typical ore sample, but it is the isotope that undergoes fission. (p. 62). Seaborg and Joe Kennedy developing a process to separate these isotopes and began to do extensive research into neutron bombardment of the separate isotopes. Ed McMillian, who also worked at the university, determined that one of the particles left over from the bombardments of U-238 did not behave in a manner characteristic of what they expected. These particular particles had a half-life of 2.3 days, which lacked a relationship to other known isotope forms of uranium. The particles also lacked mobility which would be a characteristic of lighter fission fragments. McMillian's reasoning was that some of the isotopes were absorbing the neutrons instead of undergoing fission.

With the help of Phil Abelson they determined that the behavior of this element was different than all know elements, they had indeed discovered element 93. McMillian named this element neptunium, after the planet Neptune, by followed the precedence set by uranium, after Uranus.

Seaborg (2001) brought up an interesting point about the behavior of this new element and the periodic table:

> The periodic table predicted that element 93 should be a homolog of rhenium, but its chemistry was instead similar to that of uranium. Ed reasoned that element 93 resembled uranium because there was another group of elements with similar properties, like the lanthanides. If this group started with uranium, it would be called the uranides, by analogy to the lanthanide name. (p. 67).

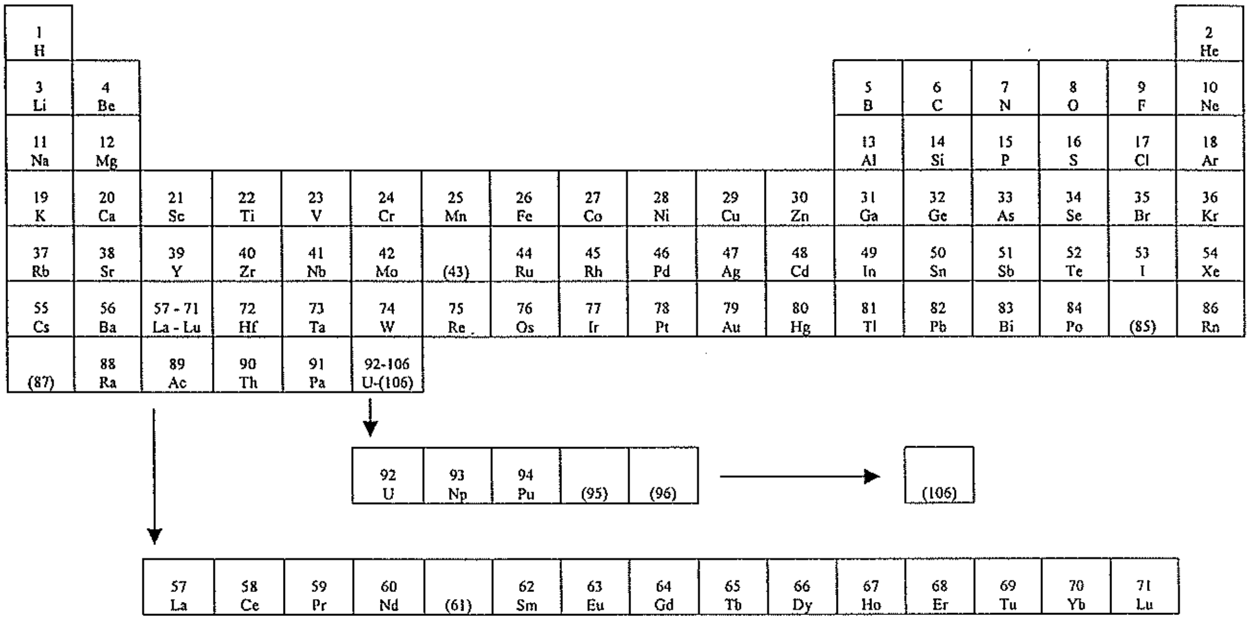
It was then assumed, by McMillian, that element 94 would be similar to uranium; as was element 93. McMillian would begin the work looking for element 94, but the war would pull him off the project and off to MIT to work on radar. It would be Glenn Seaborg, Joe Kennedy, and Arthur Wahl who would take over the work of Ed McMillian. Seaborg (2001) explained his thoughts about element 94:

> …we were aware early on the element 94 could be a big prize. The prospect of synthesizing new elements was exhilarating from a scientific standpoint, but our search held even greater potential consequences. Element 93 was too short-lived to have many practical application, but if element 93 were decaying into element 94 in the way we suspected, then 94 could be very interesting...the addition of a neutron to U-238 seemed to

> be affecting the stability of its nucleus in a completely different way. Apparently, it was changing U-238 into the odd-numbered U-239-an unstable configuration-so a neutron was transmuting to a proton, the element transmuting to 93-239. If 93-239 then transmuted to 94-239, the latter would be similar to U-235 in its proton-neutron relationship. Therefore, it would likely be similarly fissile. (p. 68-69).

Using knowledge of valency (oxidation states) they were able to isolate a particle that did not behave like any other element, they had discovered element 94. Following precedence they named the new element plutonium, after the planet Pluto. Unlike McMillian and Abelson who had published the discovery of element 93 in *The Physical Review, 1940*; Seaborg, Kennedy, and Wahl were not allowed to publish the discovery of element 94. It was 1941 and the world was at war; and unlike element 93 which had no practical application, element 94 could potentially be made into a weapon making information about its existence dangerous to release. It would be four years before the discovery was released. Seaborg and others would go to work for the war department and would play a major role in the development of the nuclear bombs, a program called the Manhattan Project. It would be a uranium-235 bomb and a plutonium bomb that would be drop on Japan in 1945 that ended the war. An interesting regional point to add is that it was Glenn Seaborg who designed the chemical process at Hanford located in south-central Washington State and over saw the technical part of the construction. Hanford was built to synthesize the plutonium from U-238 (waste product from Oak Ridge Tennessee after U-235 was removed).

Seaborg (1996) noted that neptunium and plutonium behaved very similar to uranium; like was predicted by McMillian, and not rhenium and osmium as the periodic table (*Figure 21, pg. 57*) would suggest. It was then thought that uranium, neptunium, and plutonium formed a series all themselves called the "uranide" series seen in Figure 22.



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	(43)	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 - 71 La - Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	(85)	86 Rn
(87)	88 Ra	89 Ac	90 Th	91 Pa	92-106 U-(106)												

92 U	93 Np	94 Pu	(95)	(96)	(106)

57 La	58 Ce	59 Pr	60 Nd	(61)	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb	71 Lu

Figure 22. Periodic Table with "Uranide" Series (1941-1944)

Following the pattern of the periodic table would suggest that elements 95 and elements 96 would be like those of neptunium and plutonium but they were not.

Seaborg (1996) tells about his idea:

> These assumptions proved to be wrong and the experiments directed toward the discovery of elements 95 and 96 on this basis failed. Again the undiscovered elements 95 and 96 apparently refused to fit the pattern indicated by this Periodic Table (*Figure 22*). Then, in 1944, I conceived

> the idea that perhaps all the known elements heavier than actinium were misplaced on the Periodic Table. The theory advanced was that these elements heavier than actinium might constitute a second series similar to the series of 'rare-earth' or 'lanthanide' elements (*Figure 23*)…The new concept meant that elements 95 and 96 should have some properties in common with actinium and some in common with their rare-earth 'sisters', europium and gadolinium…when experiments were designed according to this new concept, elements 95 and 96 were soon discovered. (p. 3901).

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	(43)	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 - 71 La - Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	(85)	86 Rn
(87)	88 Ra	89 - 96 Ac-(96)															

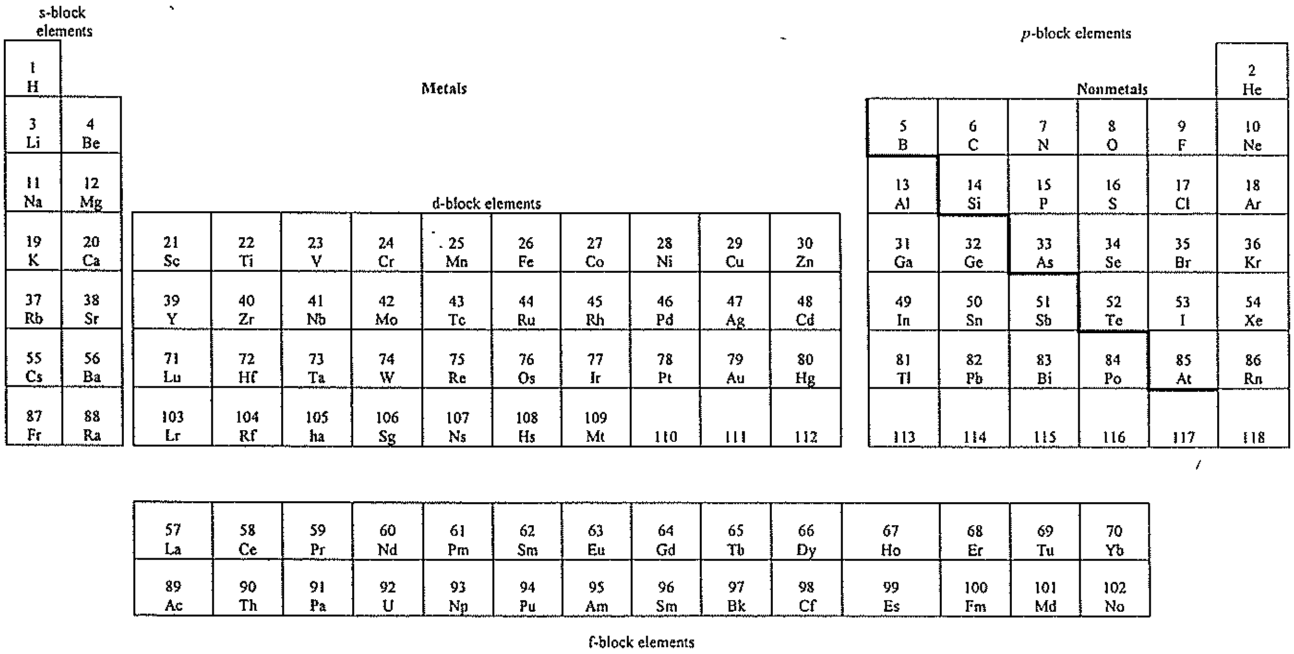
57 La	58 Ce	59 Pr	60 Nd	(61)	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95	96							

Figure 23. Periodic Table of Glenn Seaborg's Actinide Series (1944 -1945)

This would not be the end, by 1961 elements 97 to 103 were discovered using this design of the table, and as a result the elements heavier than 103 would be placed on table where thorium, protactinium and uranium were previously held. The elements from 104 (rutherfordium) up to number 118 are termed 'transactinides' and are placed in their positions on the modern periodic table in Figure 24. The four missing elements 43, 61, 85, and 87 would all be discovered as trace elements (fission products), none of them occur naturally in the Earth's crust to any appreciable amount.

Seaborg (1997) provided these thoughts two years prior to his death:

> This form of the periodic table is accepted throughout the world and is now ubiquitous in wall charts and chemistry books. I am, needless to say, proud that U.S. chemists recommended that element 106, which is placed under tungsten (74), be called "seaborgium." I am looking forward to the day when chemical investigators will refer to such compounds as seaborgous chloride, seaborgic nitrate, and perhaps, sodium seaborgate. Fortunately, this name, after initial rejection, is now being accepted by the Commission on Nomenclature on Inorganic Chemistry of the Union of Pure & Applied Chemistry (IUPAC). (p. 3).



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 ha	106 Sg	107 Ns	108 Hs	109 Mt	110	111	112	113	114	115	116	117	118

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Sm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Figure 24. Modern Periodic Table (1950 - Present)

International Union of Pure & Applied Chemistry (IUPAC)

Holden (2004) mentioned that the International Union of Pure & Applied Chemistry (IUPAC) was formed during the early part of the 20th Century, 1920's. IUPAC's purpose is to provide the means of international standardization of all quantitative and qualitative data related to the respective field. They are of today what the first international science conference; Congress at Karlsruhe, was to the science world of 1860. One of the major issues facing pre-IUPAC committees was the standardization of the atomic weight scale. Dalton first proposed a scale based upon H =1 at the beginning of the 19th Century, and it was used for a period of 100 years. The O = 16 standard began to appear regularly at the end of the 19th Century. Entering into the new Century the debate was in full swing. The hydrogen proponents argued that hydrogen had the advantage because it was the lightest atom known and that it was used as the standard for gas density. It was also easier for teachers to explain to students. The oxygen proponents argued that oxygen was the experimental standard already used to establish atomic weights. In fact, hydrogen's atomic weight was determined by the H/O relationship. Every atomic weight determined was some how related to oxygen, its bonding ratio was one of the standards used to calculate valency. A 1906 vote went in favor of oxygen as a standard and this would be the case for 30 years. The discovery of the neutron in 1932 would make H =1 an impossible choice to use as a reference atom because it did not contain any neutrons. The discovery of two isotopes of oxygen in 1929 made things a little messier as well. Chemists used oxygen calculations based upon water O =16 (average oxygen mass); whereas, physicist's scale 16 O = 16 (individual isotopic mass) was based upon oxygen in the air. These two systems would have slight differences in calculated values and instead of trying to make a uniform system out of them, both were accepted and used by their respective fields.

Alfred Nier proposed a new possible scale in the early 1950's, this scale was based upon C =12, not a new idea as mentioned earlier, Gustavus Detlef Hinrichs proposed this scale in 1893. Neir would single handedly determine all the new values based upon this system. He presented his tables to Edward Wichers, who had solicited proposals for alternate systems, and Josef Mattauch. Wichers and Mattauch would embrace the new system enthusiastically and each would make a world-wide effort in the late 1950's to adopt the system. Mattauch would focus on the physicist's approval, and Wichers would seek out the chemists. Following the approval of the International Union of Pure and Applied Physics (IUPAP) General Assembly at Ottawa, Canada in 1960 and the IUPAC General Assembly at Montreal, Canada in 1961, the atomic weights were officially given the 12 C = 12 scale for the first time in the 1961 report" (Holden, 2004, pg. 14). Petley, B.W. (1996) mentioned that the new atomic mass standard would be called the unified atomic mass unit (symbol, u) and is equal to one-twelfth the mass of the nucleus of the carbon-12 atom, this would be the value used to compare the atomic masses of all other elements.

Emsley (1998) pointed out, "The periodic table has its dark side. It has led chemists astray, as it did with the tellurium/iodine paradox; it still has its unresolved tensions, and more recently it has led to bitter disputes." (p. 277). In the 1970's and 1980's attempts were made to resolve a group numbering conflict that occurred between the European table and the American table. The European table listed the group names on the left half from IA to VIIIA and then the IB to VIIB on the right with the noble gases being 0. The American table listed the *s* and *p* groups as the IA to VIIIA and listed the transitions elements as the B groups. IUPAC suggested that the groups be numbered 1 through 18; a proposal initially was made by Arne Olander, 40 years earlier in the late 1950's. After getting the approval of several other organizations, like the American Chemical Society (ACS), this transition occurred. The lanthanide and actinide series were not considered for group numbers because they behave more like rows than periods. Figure 25 reflects all three of the standards used.

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA	American
IA	IIA	IIIA	IVA	VA	VIA	VIIIA	VIIIA			IB	IIB	IIIB	IVB	VB	VIB	VIIB	0	European
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	IUPAC
1 H																	2 He	
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
87 Fr	88 Ra	103 Lr	104 Rf	105 ha	106 Sg	107 Ns	108 Hs	109 Mt	110	111	112	113	114	115	116	117	118	

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Sm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Figure 25. American/European/IUPAC Systems of Group Numbers

According to Holden (2004) the biggest conflict within IUPAC would be in the area of nomenclature, especially with the synthesis of 1960's and 1970's elements 104, 105, and 106 by the Lawerence Berkeley Laboratory in the USA and the Joint Institute for Nuclear Research in Dubna, USSR. New concerns would arise in the 1980's with the newly synthesized elements 107, 108, 109 as well and this would bring into the conflict the Institute for Heavy Ion Research in Darmstadt, Germany. Each facility claimed some priority, each institute named the elements differently, and each had issues with the results of others, it would be up to IUPAC and IUPAP to resolve the mess.

Parrington, J.R., et al (1996) stated that in 1985 IUPAC and IUPAP established a special group called TWG, Transfermium Working Group, to define the criteria for discovery and to establish priority of the elements. During the time that the problem was being debated IUPAC established a provisional naming system to be used for all elements until priority has been established. The provisional naming system is based upon the elements atomic number; it uses a root name with symbol to represent the element and all will end with *–ium*. Figure 26 reflects the root names and symbols used for all future elements waiting for priority acceptance.

Number	Root Name	Root Symbol
0	nil	n
1	un	u
2	bi	b
3	tri	t
4	quad	q
5	pent	p
6	hex	h
7	sept	s
8	oct	o
9	enn	e

Figure 26. IUPAC Provisional Naming System

During the 1997 IUPAC meeting the TRW presented final recommendations and although not everybody was totally happy with the results. Figure 27 reflects the final nomenclature decisions and prior provisional name.

Atomic Number	Provisional Name	Provisional Symbol	1997 IUPAC Name	1997 IUPAC Symbol
104	un+nil+quad+ium	unq	rutherfordium	Rf
105	un+nil+pent+ium	unp	dubnium	Db
106	un+nil+hex+ium	unh	seaborgium	Sg
107	un+nil+sept+ium	uns	bohrium	Bh
108	un+nil+oct+ium	uno	hassium	Hs
109	un+nil+enn+ium	une	meitnerium	Mt

Figure 27. 1997 IUPAC Naming Solutions

Cornish, J., Rosenblatt, G.M. (2003) indicated that the (JWP) Joint Working Party (old TRW) for IUPAC and IUPAP confirmed the discovery and priority of element 110 on 16 August 2003. Element 110 would have the recommended name of darmstadtium and its symbol is Ds.

Karol, P.J., et al (2003) indicated in his report that during the IUPAC 16 August 2003 meeting priority was discussed for elements 111, 112, 114, 116, and 118. It was recommended by the JWP that priority be given to the discovery of elements 111, but no name or symbol had been assigned. Evidence for elements 112, 114, and 116 is good but not conclusive enough to confirm priority. Element 118 was retracted by it initial investigators so no action was taken.

Location Problems on the Table

According to Emsley (1998) hydrogen and helium present an interesting dilemma. Hydrogen has a configuration of 1*s* which places it in the *s* block elements above lithium 2*s*, but unlike the other entire *s* block elements which are metals; hydrogen is a nonmetal. Helium has the very similar concern, it configuration is of 2*s* so it should be placed in the 2*s*-block above magnesium, but its properties are such that it is definitely a noble gas.

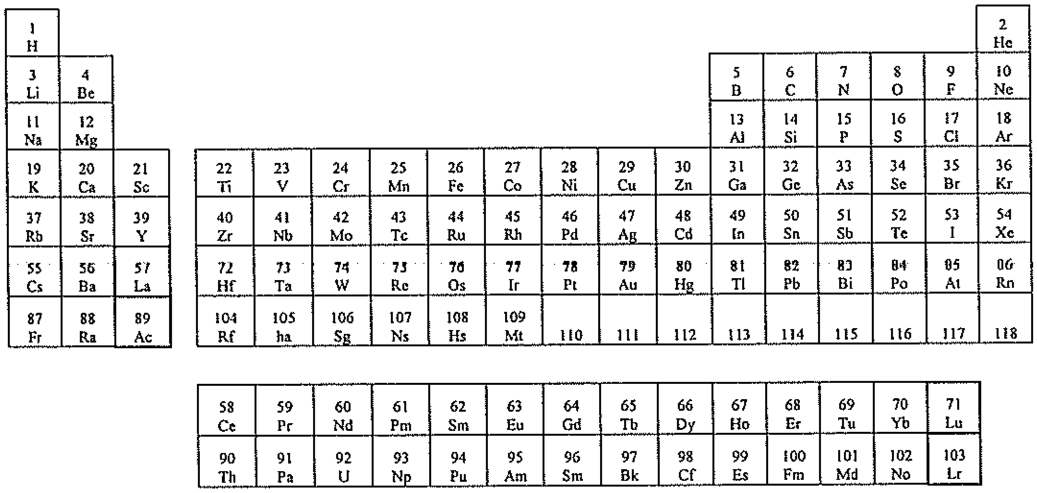
Emsley (1998) points out some solutions to the problem:

> Some tables place hydrogen by itself, or with helium, in the very centre of the table, floating free above the other elements. Others place hydrogen above fluorine, although it shares little in common with the halogen gases. Some authors give it double billing and place it above both lithium and fluorine. (p. 281).

Also mentioned by Emsley (1998) was the *f*-block controversy. The lanthanide elements and actinide elements have been pulled out of the table and placed on the bottom for reason of space. Which elements begin these blocks varies from author to author. Mazurs (1957) stated that research done by V.I. Gol'danskii reflected, "one half of the cited authors placed Sc and Y over Lu and Lw in group IIIB of the transition elements, and the other half placed them with the inner transitions over La and Ac." (p. 90).

Spronsen (1969) also noted, "Villar *(German E.)* maintained that lanthanum and actinium were not homologues of scandium and yttrium. He inclined, rather to analogies between these elements and lutetium and lawrencium, notably on the basis of a formula he constructed." (p. 321).

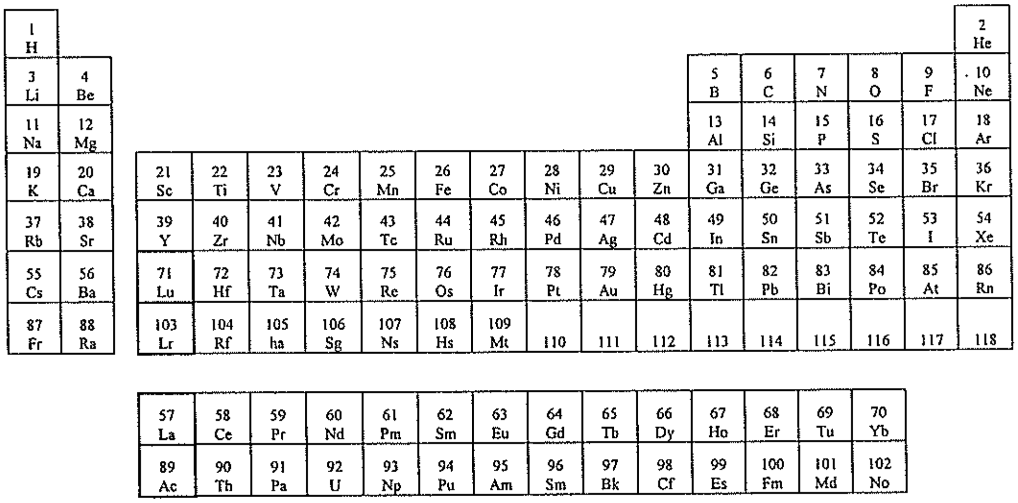
Glenn Seaborg (2001) was one of the scientists who felt that the lanthanide series and actinide series should begin with Ce and Th and end with Lu and Lr based upon researchers earlier experimental data as reflected in Figure 28.



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 ha	106 Sg	107 Ns	108 Hs	109 Mt	110	111	112	113	114	115	116	117	118

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Sm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Figure 28. Initial Consideration of f-block elements



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 ha	106 Sg	107 Ns	108 Hs	109 Mt	110	111	112	113	114	115	116	117	118

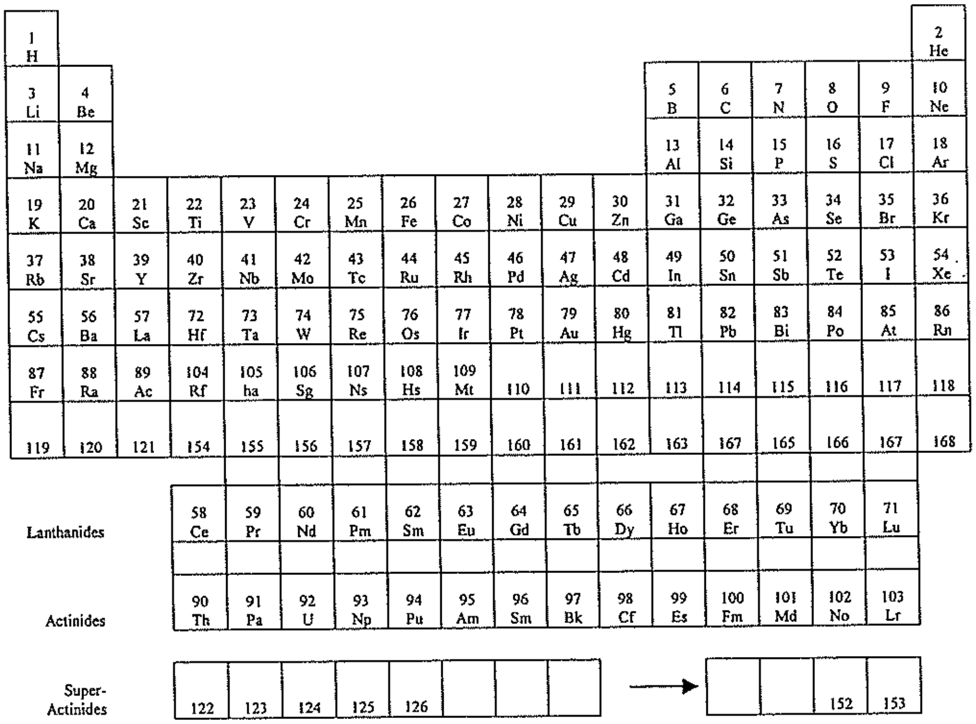
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Sm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Figure 29. Currently Most Accepted f-block Arrangement

Jensen, W.B. (1982) would conclusively state that the *f*-block elements should begin with lanthanum and actinium and end with ytterbium and nobelium, respectfully. This arrangement is reflected in Figure 29. Jenson based his conclusions on the physical evidence used to differentiate the elements by various scientists including Hamilton, Merz, and Ulmer who worked to derive a solution to the problem in the 1960's. The physical evidence included melting points, crystal structure, atomic spectra, and also superconductivity. Although tables are still being produced using both arrangements, an increasing number of scientists are adopting the latter as a standard.

Beyond the Current Table

G. Seaborg (1997) gave a glimpse of the future table. Using computer technology to predict elemental behavior of the yet undiscovered elements it was possible to expand the table to accommodate 168 elements. This would incorporate the addition of an 8th row and elements into the 8*s*-block, 8*p*-block, and 7*d*-block groups. There would be the formation of a new group that consisted of the next 6*f*-block (14 elements) and the first 5*g*-block (18 elements). These 32 elements would make up a new series that Seaborg termed "*Superactinides*" as seen in Figure 30. (Note in Figure 30 that Seaborg still placed lanthanum and actinium under scandium and yttrium and started the series with cerium and thorium.)



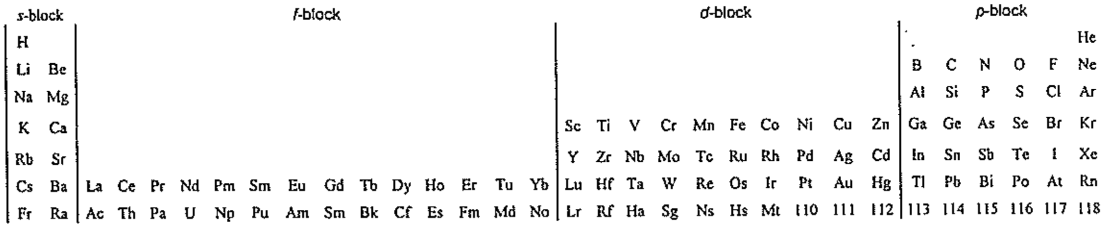
	1 H																	2 He
	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
	87 Fr	88 Ra	89 Ac	104 Rf	105 ha	106 Sg	107 Ns	108 Hs	109 Mt	110	111	112	113	114	115	116	117	118
	119	120	121	154	155	156	157	158	159	160	161	162	163	167	165	166	167	168
Lanthanides				58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tu	70 Yb	71 Lu	
Actinides				90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Sm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	
Super-Actinides				122	123	124	125	126				→				152	153	

Fig. 30 Futuristic table of Glenn Seaborg

Seaborg expressed his thoughts about the heavy elements:

> Although we can feel confident that this is the approximate form the Periodic Table should assume, we unfortunately, will not be able to verify much of this experimentally because the half-lives of the nuclei are too short and there are no nuclear synthesis reactions available to reach such heavy elements. However, I believe it will be possible to add some six new known elements (perhaps slightly more) to our Periodic Table. (p. 3904).

Karol (2002) discussed in his research that how far the table might be extended would be a question of nuclear stability for larger systems. Research has estimated that neutron stars consist of very heavy elements about Z = 10^{21}, considering our heaviest element is only Z = 110 this gives scientists the possibility of large stable nuclei. Karol used the *spdf* style periodic table but preferred the long form, as in Figure 31. He used the same structure in Figure 32 to represents a future table up to element 1138.



s-block		*f*-block														*d*-block										*p*-block					
H																															He
Li	Be																									B	C	N	O	F	Ne
Na	Mg																									Al	Si	P	S	Cl	Ar
K	Ca															Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr															Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tu	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Sm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Ha	Sg	Ns	Hs	Mt	110	111	112	113	114	115	116	117	118

Figure 31. Periodic Table of the Elements Long Form

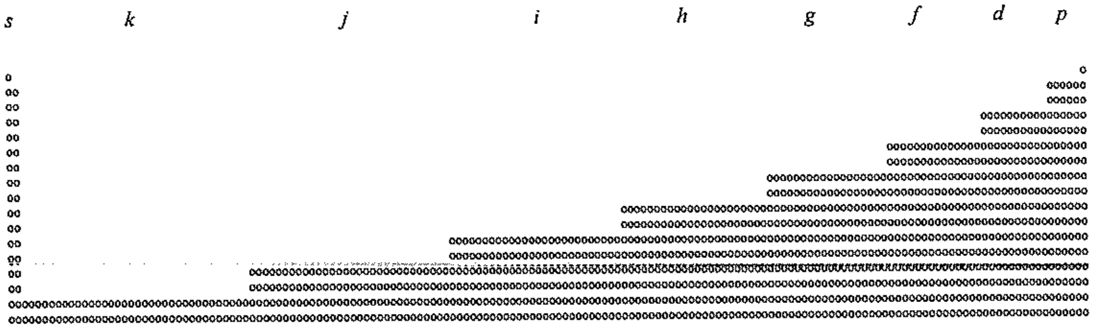


Figure 32. The Expanded Periodic Table Through Element Z = 1138

Summary

Adorning the walls of almost every science classroom, located in every science book, is the periodic table. The purpose behind this literary review was to develop this table from infancy, to present form, and to take a peek at its future. Our journey began over 2000 years ago with a debate on the structure of matter, it peeked with a debate on priority of the table, and our journey ended with a debate on who synthesized a particular element first. From the Congress of Karlsruhe to IUPAC, the strength of science has been in the ability of scientists to share, debate, and grow from one another. This review reflected how the periodic table grew in both form and ideology and how the ideas of one scientist were used as the starting point for another. It will be the scientific debates in the future that will bring forth our world of tomorrow and at the heart of our world will continue to be the periodic table.

Emsley (1998) mentioned this about the periodic table;

> The periodic table is the hallmark of inorganic chemistry. It summarizes the chemical elements in a simple yet logical table that can even be made into a work of art. As long as chemistry is studied there will be a periodic

> table. And even if someday we communicate with another part of this universe, we can be sure that one thing both cultures with have in common is an ordered system of the elements that will be instantly recognizable by both intelligent life forms. (p. 281).

Dmitri Mendeleev is given credit as the father of the periodic system, and rightfully so, but it was also the discoveries of hundreds of other great people, before him and after him, that have brought the periodic table to its present form.

CHAPTER III

DESIGN OF PROJECT

The purpose of this project was to design a professional development course focusing on the periodic table of the elements. To accomplish this purpose, Chapter three is broken up into the following sections to describe the design of the project:

1. Need for the Project
2. Procedures
3. Planned Implementation and Assessment of the Project

Need for the Project

The idea for developing a course on the periodic table was influenced by the following considerations:

1. The school year demands on middle and high school teachers are very high making the opportunities for outside research very limited and difficult.
2. The amount of information on the periodic table is quite extensive. Some teachers find it hard to separate the practical information of the periodic table from the impractical, when they are looking at curriculum development.
3. Universities typically only offer special subject science courses during the daytime and only during the regular school year. Few of these courses are offered during the summer sessions when teachers are most likely available. Science teachers are searching for course work that will enhance the classroom curriculum and strengthen the program. Science courses that are available tend to be subject

matter specific (chemistry, biology, etc.) and do not provide the classroom focus approach the teachers are seeking.

4. Teachers are being asked to teach subject matter that is outside their specialty area. As the state standards are being changed, curriculum is being shifted between grade levels. Teachers are finding themselves being asked to teach subject matter that is outside their endorsement areas.

Procedures

It is often difficult for middle and high school grade teachers to sort through all the available information on the periodic table, all the while trying to figure out what is useful and what it not; especially for those teachers who have minimal chemistry background. I began this project with trying to answer two basic questions. It was also my desire to provide myself a greater understanding of the periodic table, so that I could further develop my own chemistry curriculum.

Many chemistry textbooks show Mendeleev's original table as an introduction to the periodic table. Mendeleev's original table really does not resemble, in appearance, the modern day periodic table, yet we tell the students that the modern table is a revised version of Mendeleev's original. My first question was, "What was the historical development of the table up to Mendeleev?" I was hoping to discover what Mendeleev used to develop his first table; if I could understand the basis behind Mendeleev's table it might be easier to show my students its basic foundation. My second question was based upon the first, "What were the major changes to the table since Mendeleev?" My goal here was to visually change the table from Mendeleev to the modern periodic table, so the students could watch the progressive steps. With those two questions my literary review began.

The information that I was able to obtain came from research articles, books, online information, and laboratory manuals. Out of all the information that I initially felt might be of some benefit to this project, only about twenty-five percent of it was worth spending the time doing a more in depth review. The remaining seventy-five percent was too heavy in the chemistry for this project. I also noticed during my collection of literary material that some information lacked the specific depth I needed. It was also interesting to read through a lot of information that was so watered down, that in essence became inaccurate. The following is an example of some inaccurate information that was just published by Jim Wilson (2004);

> The story of the periodic table begins in 1863 when a young French geologist, Alexandre-Emile Begular de Chancourtois, wrote a list of the then known elements in increasing atomic weight…About the same time a young English chemist, John A.R. Newlands, was also experimenting with ways to arrange the elements. He noticed that chemical groups repeated every eight elements. Thinking he was on to something big, he proudly reported his work to the English Chemical Society. The older, more conservative members of the group branded his idea absurd, and it was pretty much forgotten. Scientific communications were slow in the 19th Century. So, it is not surprising that another 20 years passed before the idea was revived. This time the notion struck Russian chemist Dmitri I. Mendeleev and German chemist Julius Lothar Meyer. (p. 38).

Another slightly inaccurate point made by Wilson (2004);

> Now, about those odd names. Several years ago the International Union of Pure and Applied Chemistry in Research Triangle Park, N.C., decided that new elements should have culturally neutral names. To do this, they use the Latin pronunciation of an element's atomic number. (p. 41).

This article would have you believe that only a couple of people we responsible for the periodic table and its ideas. The date is wrong; twenty years after 1863 would be 1883. Mendeleev would publish his first table in 1869 and his second in 1871, by 1883 the table was pretty much being accepted throughout the scientific world. Gallium and Scandium were discovered in the 1870's and these would propel his table into history. IUPAC established a temporary naming system to use until validity and priority was determined then the discovering institution could assign a name and symbol.

My high school chemistry book Smoot, et al, (2001) also provided some inaccurate thoughts as it tried to explain the solution to the Te-I, Ar-K and Co-Ni atomic mass problem.

> Henry Moseley found the reason for these apparent exceptions to Mendeleev's periodic law. Moseley's X-rays experiments, in 1913, showed that the nucleus of each element has an integral positive charge, the atomic number. Iodine, nickel, and potassium have greater atomic numbers than do tellurium, cobalt, and argon, respectively. (p. 141).

This part would have you assume the atomic mass problem was solved by Moseley but it was the discovery of the isotopes that explained this problem. Moseley's' X-rays proved that the elements were in the right location on the periodic table, but they did not explain why the masses did not follow the periodic pattern.

Plenty of literature was available on the use of the periodic table, types of periodic tables, and different authors take on the periodic table, but very little was available on the historical development of the table. In the end my literary review was mostly based upon books instead of journal articles. Within the historical review I discovered that not all the dates matched up exactly from one author to another. This proved to be very frustrating as it required more research to develop a more exact timeline.

After I had collected enough literature to start the writing process, I begin to put together the history of the table. The challenging part to this was the development of the numerous tables that I needed to provided the visual picture I was looking for. These tables were placed in chronological order, and considering there have been over seven hundred versions of the table I had to be very selective as to which ones would serve my purpose.

The final part to the project was the development of the course itself. The foundation of the course is the historical development of the table. The major changes to the table led perfectly into the different class topics that would be addressed. I used my classroom experience as a chemistry teacher to locate some practical labs that would test the ideas presented. I also used my experiences as a graduate student at Central Washington University to develop the group project.

The methodology applied to my course proposal is the theory of Constructivism. The constructivist theory is based on observation and scientific studies based upon how people learn. In order for people to learn new material we must be creators of our own knowledge, we must ask questions, explore, and assess what we have learned. A constructivist teacher encourages their students to become "expert learners". In a well-planned classroom the students will learn *How to Learn*. The constructivist teacher will pose questions and problems, then help them to find their own answers. In my project class this will be accomplished by the following:

- Prompt students to formulate their own questions (inquiry)
- Allow multiple interpretations and expressions of learning (multiple intelligences)
- Group work and use of peer resources (collaborative learning)

According to Fosnot (1996) in a constructivist classroom learning is *constructed* by formulating ideas from knowledge, facts, and understanding. The teacher allows the students to reflect and construct their own methods of measurement. Learning is also *active*. Teachers coach, moderates, suggests, but allows the students room to experiment, ask questions, and try things that don't work. Learning requires the students' full participation. Learning is *reflective*. Students control their own learning process by reflecting on their own experiences. Learning is *collaborative*. The constructivist classroom relies a great deal on the collaboration among students, this is important because students learn from their peers. Learning is *inquiry-based*. Students use inquiry methods to investigate, question and use a wide range of resources to find solutions and answers to problems. Learning is *evolving*. The use of constructivist teaching takes into account the students current conceptions and continues to build upon them.

The Commission on Student Learning (2003) outlined the following principles related to science education. I used these principles and related EALR's as the foundation behind the project development.

> Learning in science depends on actively doing science. Active engagement in hands-on, minds-on science learning experiences enables students to make sense of the physical world, to develop answers to their questions through research and investigation, using inquiry and to design solutions to their problems using design processes. Toward these ends, the Essential Academic Learning Requirements (EALR) for science was developed based on the following set of guiding principles.
>
> - All students should be expected to attain proficient level of achievement and performance on all EALR.
> - All students should have access to a carefully articulated science program each year in kindergarten through 10th grade with opportunities for continued study in grades 11 and 12.
> - All students should receive quality feedback about their performance and achievement in science on a continuous basis.
> - All students, regardless of gender, cultural or ethnic background, physical or learning disabilities, aspirations, or interest and motivation in science, should have the opportunity to attain science literacy.

- All students should have access to effective and appropriate teaching from well-trained teachers who are supported with high quality instructional resources.

When all students are proficient in the Essential Academic Learning Requirements for science, Washington State will be much closer to attaining the Washington State learning goals including thinking and writing with logic and clarity.

Planned Implementation and Assessment of the Project

Throughout the course of the year I was constantly bringing new information into my classroom and sharing it with my students. I was able to see what new topics they understood and which ones proved to be more difficult, this testing of ideas help me to make sure that the project was staying age appropriate.

I shared my project with other science teachers in my building. They were interested in the information I discovered about the periodic table. I was asked to present, to science teachers in our district, on the periodic table during an in-service day next year. Finally, I am hoping to present my course to higher education institutions with the hope that they will allow me the opportunity to teach this project as a college course. The course will continue to develop as students discover new ideas and concepts while doing their own group research. In the end if I can get a few more students and a few more teachers to have a greater understanding of the power behind the periodic table then this project was time well spent.

CHAPTER IV

PROJECT

The Periodic Table of the Elements (PTE)

A Professional Development Course

by

Michael A. Bailey

The Periodic Table of the Elements
(PTE)

Introduction

The periodic table is used extensively in all middle and high school level science classrooms. Its historical development supports the foundations behind the grade level expectations established by the State of Washington. The idea for developing a course to specifically focus on the periodic table was influenced by the following considerations:

1. The school year demands on middle and high school teachers are very high making the opportunities for outside research very limited.
2. The amount of information on the periodic table is quite extensive and is hard for some teachers to separate the practical from the impractical.
3. Universities typically only offer special subject science courses during the daytime and only during the school year. Very few of these courses are offered during the summer sessions when teachers are most available. Many science teachers are looking for courses that will enhance their program in their classrooms, many of the science course that are offered, are subject matter specific (chemistry, biology, etc.) and do not provide the classroom focus approach that teachers need.
4. Many teachers are being asked to teach subject matter that is outside their specialty area. They are having a hard time meeting the demands of the state standards in science.

The following Washington State Essential Academic Learning Requirements for Science are supported in this class:

EALR 1

Systems: The student knows and applies scientific concepts and principles to understand systems.

Component 1.1 Properties: Understand how properties are used to identify, describe, and categorize substances, materials, and objects and how characteristics are used to categorize living things.

EARL Banner: Physical Systems

Concept Strand: Properties of Substances

GLE Coding: 1.1.1

GLE: Grade Level Expectations for 9 and 10

Understand the atomic nature of matter, how it relates to physical and chemical properties, and serves as the basis for the structure and use of the Periodic Table.

- Identify or describe how changing the number of electrons, neutrons, and/or protons of an atom affects that atom including atomic name and number.
- Identify, describe, or explain the properties shared by elements in a vertical column (groups or families) of the periodic table.
- Predict the properties of an element based on the element's location (groups or families) on the periodic table.
- Identify an unknown substance using the substance's physical and/or chemical properties.
- Explain or predict the behavior of a substance based upon its physical and/or chemical properties.
- Describe how changing the number of electrons, neutrons, protons affects that atom including atomic name and number.
- Predict and explain the properties of elements based on the elements' location (groups or families) on the Periodic Table.

EALR 1

Systems: The student knows and applies scientific concepts and principles to understand systems.

Component 1.2 Structures: Understand how components, structures, organizations, and interconnections describe systems..

EARL Banner: Physical Systems

Concept Strand: Energy Transfer and Transformations

GLE Coding: 1.2.2

GLE: Grade Level Expectations for 9 and 10

Analyze energy transfers and transformations within a system including energy conservation.

- Analyze conditions likely to transfer energy from one part of a system to another.
- Explain how chemical or nuclear reactions can absorb or release energy in a system.
- Examine and explain how energy is transferred within and among systems.
- Describe what happens to the system's total energy as energy is transferred or transformed (e.g., the sum of kinetic and potential remains somewhat constant).
- Explain and give examples of how changes in the atomic or molecular configuration can result in an input or a release of energy.
- Measure decreases and increases of energy during energy transfers in terms of energy conservation.

EALR 1

Systems: The student knows and applies scientific concepts and principles to understand systems.

Component 1.2 Structures: Understand how components, structures, organizations, and interconnections describe systems..

EARL Banner: Physical Systems

Concept Strand: Structure of Matter

GLE Coding: 1.2.3

GLE: Grade Level Expectations for 9 and 10

Analyze the relationship between the structural characteristics of atoms and how atoms <u>bond</u> to form molecules.

- Describe the characteristics of electrons, neutrons, and/or protons.
- Describe the role of the electrons, neutrons, and/or protons in atomic/molecular attractions and bonds.
- Diagram and explain what occurs at the electron level during atomic bonding.
- Predict and explain whether an atom will lose, gain, or share electrons when forming chemical bonds with another atom.

EALR 2

Inquiry: The student knows and applies the skills, and processes, and nature of scientific inquiry.

Component 2.2 Nature of Science: Understand the nature of scientific inquiry.

EARL Banner: Nature of Science

Concept Strand: Intellectual Honesty

GLE Coding: 2.2.1

GLE: Grade Level Expectations grades 8, 9, and 10

Analyze and explain why curiosity, honesty, openness, and skepticism are integral to scientific inquiry.

- Analyze and explain why curiosity, honesty, openness, and skepticism are integral to scientific inquiry.
- Describe or identify intellectually honest responses to research results.
- Explain the necessity of scientists having ethical standards for recording, reporting, and communicating results.
- Explain why peer review is necessary in the scientific reporting process.
- Explain the necessity of documenting sources of information.

EALR 2

Inquiry: The student knows and applies the skills, and processes, and nature of scientific inquiry.

Component 2.2 Nature of Science: Understand the nature of scientific inquiry.

EARL Banner: Nature of Science

Concept Strand: Limitation of Science and Technology

GLE Coding: 2.2.2

GLE: Grade Level Expectations grade 9 and 10

Evaluate factors that limit the extent of a scientific investigation or design process.

- Explain how the following factors limit the extent of scientific investigation and design processes:
- Purpose of the investigation
- Available technology
- Interests of scientists and society
- Personal bias
- Funding influences
- Societal, cultural, and personal beliefs and ways of viewing the world
- Politics
- Ethics and morality
- Justify the need for the following:
  1. Replication of the investigation.
  2. Appropriate scientific response when given two competing theories (e.g., construct investigations to test competing explanations).
  3. Evidence to support a given hypothesis.
  4. A conclusion that logically follows from the results of a given investigation.

EALR 2

Inquiry: The student knows and applies the skills, and processes, and nature of scientific inquiry.

Component 2.2 Nature of Science: Understand the nature of scientific inquiry.

EARL Banner: Nature of Science

Concept Strand: Evaluating Inconsistent Results

GLE Coding: 2.2.3

GLE: Grade Level Expectations grade 9 and 10

Evaluate divergent results from scientific investigations based on scientific arguments and explanations.

- Defend or refute explanations for the event or phenomena using evidence considering the following:
  1. experimental design and technique
  2. unexpected outside factors
  3. faulty or unsupportable connections between conclusions and data improper statistical analysis.

EALR 2

Inquiry: The student knows and applies the skills, and processes, and nature of scientific inquiry.

Component 2.2 Nature of Science: Understand the nature of scientific inquiry.

EARL Banner: Nature of Science

Concept Strand: Evolution of Scientific Thought

GLE Coding: 2.2.5

GLE: Grade Level Expectations grades 8, 9 and 10

Understand how science involves testing, revising, and occasionally discarding theories, how inquiry and investigations lead to better understanding of the natural world, and why inquiry cannot lead to absolute truth.

- Identify and explain why scientific ideas are refined or replaced over time.
- Explain why science does not give absolute answers.
- Explain how inquiry, investigations and improved technology leads to better understanding of the natural world.

EALR 3

Design: The student knows and applies the design process to develop solutions to human problems in societal contexts.

Component 3.2 Science, Technology, and Society: Understand that science and Technology are human endeavors, interrelated to each other, to society, and to the workplace.

EARL Banner: Science, Technology, and Society

Concept Strand: All Peoples Contribute to Science and Technology

GLE Coding: 3.2.1

GLE: Grade Level Expectations grades 8, 9 and 10

Analyze how scientific knowledge and technological advances discovered and developed by individuals and communities in all cultures of the world contribute to changes in societies.

- Research and report on how life has changed throughout history because of scientific knowledge and technological advances from a variety of peoples.
- Compare and contrast the impacts of diverse cultures and individuals on science and technology.

EALR 3

Design: The student knows and applies the design process to develop solutions to human problems in societal contexts.

Component 3.2 Science, Technology, and Society: Understand that science and Technology are human endeavors, interrelated to each other, to society, and to the workplace.

EARL Banner: Science, Technology, and Society

Concept Strand: Relationships of Science and Technology

GLE Coding: 3.2.2

GLE: Grade Level Expectations grades 8, 9 and 10

Analyze how the scientific enterprise and technological advances influence and are influenced by human activity

- Examine how science and/or technology have led to specific societal or economic development.
- Compare and contrast advantages and/or disadvantages of using new technology or science in terms of ethics, politics, and environmental considerations

The Periodic Table of the Elements
(PTE)

Course Syllabus

Course Number and Title: TBD – The Periodic Table of the Elements

Credit Hours: 3

Course Duration: 10 Weeks

Instructor's Name: Michael A. Bailey

Course Description: The period table is a tool that can be implemented into a variety of teaching environments. This course is designed to discuss the historical development of the periodic table and provide strategies and instructional activities that can be implemented into the classroom. PTE students will develop the individual links between what they learn and what they will teach in relationship to their individual needs. It provides the opportunity to discuss appropriate activities, strategies, and programs in a teaching area related to the content area being studied.

Course Requirements: This course is open all individuals who wish to learn more about the periodic table of the elements.

Methodology: This course is designed upon the constructivist model of learning. The course itself will allow the students to be active creators of their own knowledge. Daily course content is based upon learning that is constructed, active, reflective, collaborative, inquiry-based and evolving.

Course Rationale: This course uses the constructivist model of learning in which students will interact with their physical and social environments to obtain and create new knowledge.
This course will be consistent with the following educational foundations:

- "Docendo Discimus" (by teaching we learn)
- To prepare enlightened learners
- Facilitators of learning in a diverse world

General Objectives: As a result of successful completion of PTE, students shall:

1. Make individual connections between the modern day periodic table and its historical development.
2. Formulate relations between the various periodic tables currently in use in our learning environments.

3. Generate ideas for using the periodic table in their individual classroom environments.
4. Develop ideas for further learning.

Student Expectations:

- Be committed to attending regular class sessions.
- Work respectfully and cooperatively with others during the meetings.
- Listen to each other.
- Respect everyone's thoughts and input.
- Use every opportunity as an opportunity to learn.
- Challenge yourself every day.
- Discipline yourself so others don't have to.
- Be an active learner and participant.
- Meet all deadlines set by the instructor for completing various parts of the project.
- Have fun.

Attendance:
Class attendance is essential; please be on time, and prepared, for each session.

Specific Objectives (Outcomes): Specifically, the student shall be able to:

1. Form small learning group teams based upon similar interest.
2. Use the historical development of the periodic table to enhance their understanding of the table.
3. Use the periodic table as a teaching tool.
4. Select science content around which to develop classroom units with hands-on, inquiry based lessons.
5. Create a link between what they have learned in this course and what they will teach.
6. Develop a collection of periodic table activities for use in their classrooms.

Performance Indicators related to Objectives (Outcomes):

1. Small learning groups will present to larger group.
2. Review and build upon the historical development of the table within their small learning group environment.
3. Develop or implement an individual activity focusing on the periodic table and share with the larger group.
4. Discuss and evaluate as an individual and with the small learning group.
5. Review periodic table activities with their small learning group.
6. Develop a notebook of activities related to the periodic table of the elements.

Methods of Instruction:
The class will involve but not be limited to, direct instruction, lectures, presentations, videos, class discussions, class group work, speakers, class activities and demonstrations. Individual and group assignments will be utilized, both in and out of class. Active participation is critical for successful completion of the class and

American with Disabilities Act (ADA):
Appropriate modification will be made to accommodate the special needs of student who may be unable to access information and/or material presented in the class.

Text, Readings, Materials:
Required Books:
"The Elements (3rd Edition)", J. Emsley (1999)
"Uncle Tungsten: Memories of a Chemical Boyhood", O. Sacks (2001)
"Adventures in the Atomic Age", Seaborg, G. and Seaborg, E. (2001)
"Mendeleyev's Dream", P. Strathern (2000)
Optional Books:
"*The Periodic System of Chemical Elements*" by Van Spronsen (1969)
"A Chemist in the White House: From the Manhattan Project to the End of the Cold War" by Glenn T. Seaborg (1992)
"*Mastering the Periodic Table*" by Linda Trombley and Faye Williams (2000)

Important Internet Locations:

IUPAC, International Union of Pure and Applied Chemistry
http://www.iupac.org

IUPAP, International Union of Pure and Applied Physics
http://www.iupap.org

NSTA, National Science TeachersAssociation
http://www.nsta.org/scilinks/

OSPI, Washington State Office of Superintendent of Public Instruction.
Science Essential Academic Learning Requirements (EALRs)
http://www.k12.wa.us/curriculuminstruct/science/EALR.asp

WSTA, Washington Science Teachers Association
http://www.wsta.net/html/

NSES - NRC, National Science Education Standards
http://www.nap.edu/readingroom/books/nses/

OSPI WASL: Office of Superintendent of Public Instruction.
Washington Assessment of Student Learning
http://www.k12.wa.us/assessment/WASL/testspec.aspx

Classic Papers from the History of Chemistry:
http://maple.lemoyne.edu/faculty/giunta/papers.html

Further handouts and reading assignments will be distributed to students.

Group Project and Presentation Guidelines

Purpose: To provide an opportunity to plan and implement a grade level appropriate lesson related to the periodic table of the elements.

Written Project

Your group will plan two classroom appropriate activities which is appropriate for you targeted grade level group. The activities need to be related to the periodic table of the elements. Each activity will be typed and organized, copied, stapled, and distributed to each class member as follows:

Title Page: Activity title, group members, course name and number, grade level of targeted group.
Section 1: Identify the EALR's and GLE's related to the activity.
Section 2: Identify the Teaching methodology used in activities.
Section 3: Activities with student and teacher materials.
Section 4: Summary of activities.
Section 5: Bibliography

A minimum of ten (10) resources materials must be included in the written plan and listed on the bibliography page.

Class Presentation

Your group will have approximately one (1) hour for your presentation which should include the following:

1. Introduction of group members and theme.
2. PowerPoint or other multimedia technology must be utilized.
3. Presentation of two (2) activities to the class – class members will actually "do" each activity.
    - All members must participate
    - All necessary materials must be provided by the group.
    - Copies of all material provided to all members of the class.

Evaluation of Project and Presentation

Group members will be graded using the following rubric. Additionally, group members will complete an evaluation sheet and submit a written page stating what they felt each group member contributed to the group and how the group worked together.

Each category will be scored on the following scale:

All Criteria Met Most Criteria Met Some Criteria Met

10 9 8 7 6 5 4 3 2 1

Each section is worth 50 points for a maximum score of 150 points.

Written Assignment

Preparation: Planning is evident. Syllabus guidelines are followed. Deadlines are met.

Professional Quality: Purpose is clearly stated. Concepts clearly expressed.

Organization: Content is well organized and informative. Content runs smoothly and is focused on target age group.

Resources: Resources are used and documented correctly (APA style).

Student Perspectives: Student's ideas are accurate, pertinent, and well presented.

Mechanics

Sentence Structure: Sentences are complete and well structured. Slang is omitted.

Capitalization & Punctuation: Capitalization & punctuation are correct.

Grammar: Grammar is correct.

Spelling: Spelling is correct.

Neatness: Material is legible and nicely presented.

Presentation

Professional Quality: Purpose is clearly stated. Concepts clearly expressed. Preparedness is evident.

Organization: Introduction invites interest. Content is informative. Closing summarized the activities.

Participation: All members of the group participate equally in the presentation.

Creativity: Inviting, intriguing elements are included.

Teaching Manner: A friendly, enthusiastic demeanor is apparent. Maintain frequent eye contact with audience. Student maintains a professional appearance.

Tentative Calendar or Schedule Indicating Course Content:

Class Session #1

Class Focus: Introductions and Syllabus
Organization of Small Learning Groups
Investigating the periodic table from the philosophers to the Congress at Karlsruhe.

Group Activities: Introductions and purpose.
Group Organization of Ideas
Identifying Chemical Changes: The Seven Solution Problem

Weekly Readings:
"Mendeleyev's Dream", P. Strathern (2000)

Class Session #2

Class Focus: Investigating the early attempts at the table.

Group Activities: Investigate the Law of Conservation of Mass and Energy

Weekly Readings:
"Mendeleyev's Dream", P. Strathern (2000)

Class Session #3

Class Focus: The Discoveries and Debate of Meyer and Mendeleev.

Group Activities: Jet Propulsion Laboratory, California Institute of Technology. Genesis Mission: Science Module – Cosmic Chemistry: An Elemental Question. http://genesismission.jpl.nasa.gov/educate/scimodule/indexCC-EQ.html

Weekly Readings:
"Mendeleyev's Dream", P. Strathern (2000)

Class Session #4

Class Focus: The Discovery of the Noble Gases and their Location on the Table.

Group Activities: Group Presentations

Weekly Readings:
"Uncle Tungsten: Memories of a Chemical Boyhood", O. Sacks (2001)

Class Session #5

Class Focus: The Rare Earths

Group Activities: Group Presentations

Weekly Readings:
"Uncle Tungsten: Memories of a Chemical Boyhood", O. Sacks (2001)

Class Session #6

Class Focus: The Atomic Number and H.G.J. Moseley

Group Activities: Group Presentations

Weekly Readings:
"Uncle Tungsten: Memories of a Chemical Boyhood", O. Sacks (2001)

Class Session #7

Class Focus: Isotopes and Isotopic Abundance Calculations

Group Activities: Group Presentations; Isotopic Calculations

Class Session #8

Class Focus: The Electronic Configuration and Reorganization of the Table

Group Activities: Group Presentations
Genesis Education: Cosmic Chemistry – An Elementary Question

Weekly Readings: *"Adventures in the Atomic Age*", Seaborg, G. and Seaborg, E. (2001)

Class Session #9

Class Focus: Glenn Seaborg and the Actinide Series

Group Activities: Group Presentations
Group and Family Association on the Periodic Table

Weekly Readings: *"Adventures in the Atomic Age*", Seaborg, G. and Seaborg, E. (2001)

Video: "*Trinity and Beyond - The Atomic Bomb Movie" (1999) by* Goldhil Home Media

Class Session #10

Class Focus: The Current Table and the Issues of IUPAC

Group Activities: Group Presentations
Trends of the Periodic Table

Class Session #1

Class Focus:

1. Introductions and Syllabus
2. Organization of Small Learning Groups
3. Investigating the periodic table from the philosophers to the Congress at Karlsruhe.

Group Activities:

4. Introductions and purpose.
5. Group Organization of ideas.
6. Identifying chemical changes: The Seven Solution Problem

Weekly Readings:

"Mendeleyev's Dream", P. Strathern (2000)

Key Notes included in Review of Literature:

Laboratory Activity
The Seven-Solution Problem

Scientists are problem solvers, and one of the most important ways they gain the information they need to solve a problem is by making detailed and accurate observations. Making observations is not only a key process of the experimental procedure; often, the observations made in one experiment can be applied to solving a different problem. This laboratory experiment is an example of problem solving by use of observations.

When substances are mixed together, one of two things can happen. The first is that no change occurs. The substances are stirred together but remain the same substances. The second is that a change occurs. The substances interact in some way that results in the formation of different substances. This type of change is called a chemical change, and the process or procedure that brings it about is called a chemical reaction. Sometimes, a chemical reaction is accompanied by a change that can be seen, such as a change in color, the formation of a solid, or the generation of a gas. In this experiment, you will observe the changes brought about when known substances are combined in different ways. You will then use the observations to identify the same substances when they are supplied as unknowns.

<u>Materials:</u>
Goggles
Apron
Toothpicks
Well Plate
Microplate Data Form

Procedure:
Part 1

1. Place the Microplate Data Form on your lab bench so that the numbered columns are at the top and the lettered rows are at the left.
2. Assign one of the seven known solutions to each of rows A – G.
   $AgNO_3$; NaI; $Pb(NO_3)_2$; Na_2CO_3; $Fe(NO_3)_3$; $NaOH$; $Cu(NO_3)_2$
3. In the same order as in step 2, assign a known solution to each of the columns 1-7. Write the names above the columns on the labeled Microplate Data Form.
4. The labels on your Microplate Data Form show the solutions to be mixed in each square. To avoid wasting materials, do not mix a substance with itself and do not mix the same two substances more than once. Place X's in the squares of your labeled Microplate Data Form to show where you do not need to mix solutions.

Do Not Proceed to Step 5 until the teacher has check off your Data Form.

5. Following the Microplate Data Form obtain the dropper bottles needed for each square. Only get two bottles at a time, and replace when done.
6. Holding the dropper bottle straight up and down carefully dispense 12 drops into a well plate. Add 12 drops of the second dropper bottle, making sure you do not touch the tip of the bottle with the chemical already in the well plate.
7. Stir the solutions with a toothpick, using a different toothpick for each square.
8. Examine each square for any observable changes in the solutions. Record your observations in your labeled Microplate Data Form. Where you cannot observe a change, write NR for "no reaction".
9. Discard the solutions down the drain with plenty of water.

Part 2

1. Set up another Microplate Data Form.

2. Each of the unknown solutions you will work with is identified by a letter. Using these letters (A; B; C; D; E; F; and G) assign the unknowns to lettered rows and numbered columns of the Microplate Data Form as you did for the known solutions. Mark each square where you will not mix solutions with an X.

3. Repeat the steps 6-9 of part 1. Mark careful observations and record your observations in you Microplate Data Form.

Data and Observations:

Example of Table Setup:

		$AgNO_3$	NaI	$Pb(NO_3)_2$
		A	B	C
$AgNO_3$	A	X	X	X
NaI	B		X	X
$Pb(NO_3)_2$	C			X

Conclusions:

1. Compare your observations of the known solutions with your observations of the unknown solutions. Identify one combination of known solutions and one combination of unknown solutions that clearly gave the same results and complete the sentences for all seven unknowns.

   Unknown A
   Known Solutions of ____________ + Known Solution of ______________ Produced ______________

   Unknown Solution of ___________ + Unknown Solution of ____________ Produced ______________

2. Complete the following table:

Unknown Solution		Name of Substance
A	=	__________
B	=	__________
C	=	__________
D	=	__________
E	=	__________
F	=	__________
G	=	__________

3. What different types of changes did you observe that can indicate a chemical reaction has occurred?
4. According to your observations, how many different chemical reactions occurred among the known solutions?

***Teacher Guide*:**

Intended Grade Level – Middle School or 9th Grade Science

Materials:

0.1 M solutions of the following compounds are needed:

$AgNO_3$; NaI; $Pb(NO_3)_2$; Na_2CO_3; $Fe(NO_3)_3 \cdot 6H_2O$; NaOH; $Cu(NO_3)_2$

Procedure Hints:

1. Before proceeding, be sure students have read and understood the purpose, procedure, and safety precautions for this laboratory activity.
2. You might want to precede this lab with a brief introduction to chemical reactions, a topic that is not fully covered until later in the course. To avoid misconceptions, you can not that not all chemical reactions are accompanied by changes visible to the naked eye nor do visible changes always indicate chemical reactions.
3. The experiment itself does not take a great deal of time. The most time is spent in planning, observing, and analyzing the results. Encourage students to test their identifications of the unknowns by experiment before giving you're their final list.
4. Do not use the same letter code for the unknown solutions form class to class or from year to year.
5. Remind students not to lean onto the plastic wrap with solutions on it.

Class Session #2

Class Focus: Investigating the early attempts at the table.

Group Activities: Investigate the Law of Conservation of Mass and Energy

Weekly Readings:
"Mendeleyev's Dream", P. Strathern (2000)

Key Notes included in Review of Literature:

Laboratory Activity
Investigating the Law of Conservation of Mass-Energy

A scientific law describes a phenomenon of nature. One of the basic laws of science that concerns chemists is the law of conservation of mass-energy. This law states that mass (matter) and energy are always conserved in reactions and that their sum cannot be increased or decreased. Mass and energy can be converted from one form to another.

In this investigation you use the scientific method to test the law of conservation of mass-energy. To test this law, you will carefully determine the mass of two compounds, called reactants, and allow them to react. After performing the steps in the procedure to your two products, you will then interpret your results to see if they support the law of conservation of mass-energy.

Compound A + Compound B → Compound C + Compound D
Reactants *Products*

Objectives:
In this experiment, you will

- Measure the mass of compounds A and B,
- Combine these two compounds and observe how they react,
- Determine the mass of the products formed in the reaction, and
- Interpret your results based on the law of conservation of mass-energy.

Equipment:
Goggles and Apron
2 Beakers (100 ml)
Balance
Hot Plate
Funnel and filter paper
Forceps

Procedure:

1. Prepare a data table as directed in the Analysis.
   Caution: You will be working with unknown compounds; avoid skin and eye contact, do not inhale fumes, wear goggles and lab apron.
2. Obtain a clean, dry 100 mL beaker and label it beaker 1. Measure its mass to the nearest 0.01 g.
3. Obtain compound A from your teacher and place in beaker 1. Measure the mass of beaker 1 with compound A to the nearest 0.01 g. Add 15 mL of distilled water to beaker 1, swirl the solution until the solid has dissolved. (Gently heat the solution if necessary to completely dissolve)
4. Obtain another clean, dry 100 mL beaker and label it beaker 2. Measure its mass to the nearest 0.01 g.
5. Obtain compound B from your teacher and place in beaker 2. Measure the mass of beaker 2 with compound B to the nearest 0.01 g. Add 20 mL of distilled water to beaker 2, swirl the solution until the solid has dissolved. (Gently heat the solution if necessary to completely dissolve)
6. Slowly add solution B (beaker 2) to solution A (beaker 1), in small portions. Stir the mixture continuously and gently.
7. Rinse beaker 2 with distilled water. Empty the washings into beaker 1.
8. Heat the contents of beaker 1 to the boiling point.
9. Turn off the heat and let the solid material in the beaker settle. The solid material produced is called a *precipitate*.
10. Measure the mass of a piece of filter paper to the nearest 0.01 g. Place the filter paper in the funnel and place the funnel in a support ring as shown.
11. Place the empty beaker 2 under the funnel and decant the liquid into the funnel. Keep as much of the precipitate in the beaker as possible.

12. Add 15 to 20 mL of distilled water to the precipitate, warm slightly, and swirl for about 30 seconds. Decant the liquid into the funnel.
13. Again add about 15 mL distilled water to the precipitate, warm, swirl, and decant into the funnel.
14. When the filtering is complete, use the forceps to remove the filter paper from the funnel and place it in the beaker 1 with the precipitate. Place the beaker 1 with filter paper in the fume hood under the light.
15. The contents of beaker 2 can be rinsed down the drain with plenty of water. Your teacher will provide for the mass of compound D, it is not necessary for everybody to evaporate their filtrate solution.
16. When beaker 1 and the filter paper are dry, measure their masses carefully to the nearest 0.01 g.
17. Place the solid product in beaker 1 into the waste container designated by your teacher.

Analysis:

Prepare a table to organize your data.

Reactants:

Mass of Beaker 1 __________ g

Mass of Beaker 1 and Compound A __________ g

Mass of Compound A __________ g

Mass of Beaker 2 __________ g

Mass of Beaker 2 and Compound B __________ g

Mass of Compound B __________ g

Total Mass of the Reactants

Compound A + Compound B __________ g

Products:

Mass of Filter Paper __________ g

Mass of Filter Paper + Beaker 1

+ Compound C (dry) __________ g

Mass of Compound C __________ g

Mass of Compound D (from teacher) __________ g

Total Mass of the Products

Compound C + Compound D __________ g

The difference between the mass of reactants and the mass of products =

(Compound A + Compound B) - (Compound C + Compound D) = __________ g

Conclusions:

1. What did you determine to be the difference between the mass of the reactants and the mass of the products?
2. What should the difference be according to the law of conservation of mass-energy?
3. If your experimental results do not agree with the theoretical values, cite the reasons for the difference. Your reasons should include any experimental errors you may have made.
4. In nuclear reactions there is often a measurable difference in the mass of the reactants and the mass of the products that is not the result of errors in the massing. What is the reason for the difference in mass value?

***Teacher Guide*:**

Intended Grade Level – 9th Grade Science and 10th Grade Science

Materials:

1.0 grams of KI
.99 grams of $Pb(NO_3)_2$

Procedure Hints:

1. Lead compounds are highly toxic. Caution students on handling unknown compounds.
2. It is assumed that all the $Pb(NO_3)_2$ will be used.
3. Silver Nitrate can be substituted for if cost is no a limiting factor, however Silver Nitrate is also poisonous, and can cause burns.
4. The reaction is $2\ KI + 1\ Pb(NO_3)_2 \rightarrow 1\ PbI_2 + 2\ KNO_3$
5. The solid PbI_2 should be placed in a container designated for dry landfill disposal.

Class Session #3

Class Focus: The Discoveries and Debate of Meyer and Mendeleev.

Group Activities: Jet Propulsion Laboratory, California Institute of Technology. Genesis Mission: Science Module – Cosmic Chemistry: An Elemental Question. http://genesismission.jpl.nasa.gov/educate/scimodule/indexCC-EQ.html

Weekly Readings:
"Mendeleyev's Dream", P. Strathern (2000)

Key Notes included in Review of Literature

Introduction to Genesis:

Genesis education modules are written for K-12 classroom teachers and capture student interest by using the Genesis mission as a real-world link. Aligned with the content, instruction, and assessment guidelines set forth by the National Research Council, Genesis science modules can be easily inserted in place of traditional units within a typical secondary school science curriculum. Enjoy a variety of educational products for home and school, including online lesson plans, teacher guides and student activities, suggested assessments, and lists of additional resources and references. Genesis in Education connects the intriguing real-world science of the mission to classroom instruction—there's something of interest for every educator.

Group Activity:
Have students log on to computers and do the Mendeleev Simulation.

1. Go to - http://genesismission.jpl.nasa.gov/
2. Click, *Classrooms Link*
3. Click, + *Science Modules*
4. Click, *Cosmic Chemistry: An Elemental Question*

Review Introduction Material
1. Click and Print, *Module Overview*
2. Click and Print, *Teacher and Student Guides* for reference.

Activities
1. The Search for Critical Questions
2. Making Sense of the Elements
3. Modeling the Periodic Table
4. Mendeleev and the Periodic Table – Text Review

Class Session #4

Class Focus: The Discovery of the Noble Gases and their Location on the Table.

Group Activities: Group Presentations
Review Activities from, "*Mastering the Periodic Table*", by L. Trombley and F. Williams

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Weekly Readings:
"Uncle Tungsten: Memories of a Chemical Boyhood", O. Sacks (2001)

Activity from, "*Mastering the Periodic Table*" by Linda Trombley (2000)

Directions: Use the chemical symbols given in the "Across" and "Down" clues to determine each element name. Write the element name on the line by the chemical symbol for each metal. Then write the element name in the puzzle.

Please note: Content on this page was redacted due to copyright concerns.

Activity from, "*Mastering the Periodic Table*" by Linda Trombley (2000)

Directions: Write the names and symbols of the seventeen nonmetals in the chart below. Then find each nonmetal name in the puzzle that follows and circle it. Answers can go up, down, or diagonally.

Please note: Content on this page was redacted due to copyright concerns.

Activity from, "*Mastering the Periodic Table*" by Linda Trombley (2000)

Directions: Below is a section of the periodic table that is out of order. First, use the clue in each box to figure out the name of the element and write its name in the box. Then, find the section represented by the boxes below on the real periodic table. Write the element names in their proper order in the section marked "Corrected Table." Don't leave out any elements!

Please note: Content on this page was redacted due to copyright concerns.

Class Sessions #5, #6, and #7 are linked together.

Class Session #5

Class Focus: The Rare Earths

Group Activities: Group Presentations

Weekly Readings:
"Uncle Tungsten: Memories of a Chemical Boyhood", O. Sacks (2001)

Class Session #6

Class Focus: The Atomic Number and H.G.J. Moseley

Group Activities: Group Presentations

Weekly Readings:
"Uncle Tungsten: Memories of a Chemical Boyhood", O. Sacks (2001)

Class Session #7

Class Focus: Isotopes and Isotopic Abundance Calculations

Group Activities: Group Presentations; Isotopic Calculations

Key Notes for Class Sessions #6, #7, and #8
Supporting Notes in Review of Literature

Origins of Atomic Theory

A. *Early Greek Philosophers*
   1. *Aristotle (384 – 322 $_{BC}$)* and Plato *(428 – 348 $_{BC}$)* - believed the matter was infinitely divisible.
   2. *Democritus (460 - 370 $_{BC}$)* - argued that matter is composed of small, indivisible particles which he called *atomos*, meaning, "indivisible".
   3. *Epicurus (341 – 271 $_{BC}$)* – attributed mass to atoms.
   4. *Asklepiades (≈ 100 $_{BC}$)* – introduced the idea of clusters of atoms, corresponding to what we know call molecules.
   5. Most of those in the mainstream of enlightened thought rejected or remained ignorant of the atomic theory proposed by Democritus. The concept that matter is infinitely divisible held up until the 19th century and then scientists started to rethink Democritus's notion.

B. *John Dalton and His Atomic Theory*

1. *John Dalton, an English Schoolteacher, (1766 - 1844)* published the first meaningful atomic theory. Daltons' theory was designed to explain several experimental observations.
2. Four postulates summarize Daltons' Theory:
   #1 *Each element is composed of extremely small particles called atoms.*
   #2 *All atoms of a given element are identical; the atoms of different elements are different and have different properties (including different masses).*
   #3 *Atoms of an element are not changed into different types of atoms by chemical reactions; atoms are neither created nor destroyed in chemical reactions.*
   #4 *Compounds are formed when atoms of more than one element combine; a given compound always has the same relative number and kind of atoms.*
3. Daltons' theory provides a conceptual picture of matter:
   a. **Atoms** are the basic building blocks of matter. They are the smallest unit of an element. (postulate #1)
   b. An **element** is composed of only one type of atom. (postulate #2)
   c. **Compounds** are atoms of different elements combined in definite arrangements.
   d. **Mixtures** do not involve the same interactions between atoms that are found in compounds.
4. Daltons' theory explains several laws of chemical combinations:
   a. **Law of Constant Composition** - *Joseph Louis Proust (1754 – 1826)* - in a compound, the relative number of and kind of atoms are constant. (postulate #4)
   b. **Law of Conservation of Mass (Matter)** – *Antoine Lavoisier (1743 – 1794)* - the total mass of material present before and after a chemical reaction is the same. (postulate #3)
5. Dalton predicted a new theory:
   Law of Multiple Proportions - if two elements A and B combine to form more than one compound, then the masses of B that can combine with a given mass of A are in the ratio of small whole numbers.

   H_2O (water) - 8 grams of Oxygen: 1 gram of Hydrogen
   H_2O_2 (hydrogen peroxide) - 16 grams of Oxygen: 1 gram of Hydrogen

   The ratio of oxygen to hydrogen is 2:1 by mass in the two compounds.

Protons, Neutrons, and Electrons: A Historical Perspective

By 1850 scientist had started to collect data that indicated the atom was composed of even smaller particles than how Dalton and his contemporaries viewed it (an indivisible object, like a tiny, indestructible, unchangeable ball).

Electricity

1. Two types of electric charge had been discovered by the time of *Benjamin Franklin (1706 –1790)*. He named them *positive (+)* and *negative (-)*, because they appear as opposites and can neutralize each other.
2. In order to understand the current model of atomic structure a basic rule regarding the behavior of electrically charged particles needs to be keep in mind:
   Like charges repel each other; unlike charges attract.

Radioactivity

1. In 1895, *Wilhelm Roentgen* discovered that when cathode rays struck certain materials a new type of invisible ray was emitted.
   a. This new ray passes uninterrupted through many objects.
   b. Unaffected by magnetic fields.
   c. Produced an image on photographic plates.

2. This new high-energy radiation is called *X-rays*.
3. In 1896, *Henri Becquerel (1852 – 1908)* had been studying substances that become luminous after exposure to light (phosphorescence). While working with a phosphorescent uranium mineral he discovered that even in the dark the mineral produced high-energy radiation.
4. *Marie (1867 – 1934) and Pierre Curie* began (at Becquerel's suggestion) their famous experiments to isolate radioactive components of the minerals. They were able to isolate polonium (named after her home country of Poland) and radium, which also emitted the same kind of rays as the uranium mineral. She named this phenomenon **Radioactivity** (the spontaneous emission of radiation), and substances that displays this properties are said to be radioactive.
5. *Ernest Rutherford (1871-1937),* after further study of radioactivity, revealed three types of radiation

$AlphaParticleRadiation(\alpha);$	$2^{+} Charge;$	${}^{4}_{2}He^{2+}$ *(helium atom)*
$BetaParticleRadiation(\beta);$	$1^{-} Charge;$	${}^{0}_{-1}e$*(electron)*
$GammaRadiation\ (\gamma);$	$NoCharge\ or\ mass;$	$x-rays$

6. Radioactivity showed that if atoms can break apart (emit radiation), then there must be something smaller than an atom; that is, atomic structure must involve subatomic particles.

Electrons

1. *Michael Faraday (1791 – 1867)* work with electrolysis help to determine that electricity must have a fundamental particle. This particle was given the name **electron.**
2. *Cathode rays tubes (1855 - 1896)* - used to study electrical discharge through a vacuum tube.
    a. High voltage in the tube produced radiation within the tube, known as cathode rays, (because they originated from the negative electrode, or cathode).
    b. This radiation traveled in a straight line.
    c. The radiation could not be seen but caused some materials to give off light (fluoresce).
    d. In the presence of magnetic and electrical fields the cathode rays bent in a fashion that would indicated the presence of a negatively charged particle. Electrons have been proven to exist.
    e. Cathode rays are the principle tool in current television and computer moniter images production.

3. *Sir Joseph John Thomson (1856 – 1940)* used electrical and magnetic charges to determine the charge-to-mass ratio for the particles of the beam. He was not able to calculate the charge or mass of an individual electron but his results suggested that electrons are present in all kinds of matter and that they exist in atoms of all elements.

   Charge to mass ratio = 1.76×10^{8} coulombs/gram
4. *Robert Millikan (1868 – 1953)* performed an experiment known as the "*Millikan oil-drop experiment*" to calculate the charge of an electron and thereby scientists to calculate its mass.

   Charge of an electron = $-1.60217733 \times 10^{-19}$ Coulombs
   Mass of an electron = 9.109389×10^{-28} grams

Protons

1. Using a special cathode-ray tube (**Canal Rays**) with a perforated cathode a positively charged particle was detected. These were considered to be the fundamental, positively charged particles of atomic structure.

2. Ernest Rutherford called them **protons**, from the Greek word meaning "the primary one".
3. The mass of the proton was determined to be 1.672623 x 10^{-24} grams. The charge was determined to +1.

Neutrons

1. Atoms normally have no charge; the number of protons must equal the number of electrons in an atom. Most atoms displayed masses greater than the predicted values. This lead to the indication that a third, but neutral, particle might exist.
2. In 1932, James Chadwick (1891 – 1974) produced these particles and detected them by having them knock hydrogen ions out of paraffin. This particle has been named the **neutron**.
3. The mass of the neutron was determined to be 1.6749286 x 10^{-24} grams, slightly heavier than the proton.

The Nucleus of the Atom

1. In the early 1900's J.J. Thompson proposed the first model for the structure of the atom. He proposed that an atom consisted of a sphere of positive matter in which electrons were embedded. His model became known as the "plum-pudding" model.
2. In 1910, Rutherford, his associate, Hans Geiger (1882 – 1945) and a student, Ernest Marsden sent alpha particles at gold foil to measure the angles which the particles were scattered. Rutherford predicted only slight scattering should occurred, but they found deflection at large angles.

Rutherford later described this unexpected result by saying "It was about as credible as if you had fired a 15-inch [artillery] shell at a piece of paper and it came back and hit you."

   a. Rutherford observed that most of the alpha particles passed directly through but a few were deflected in all sorts of directions. This led to the downfall of the J.J. Thompson model of the atom.
   b. Rutherford proposed that all the positive charges reside in a very small, dense region which he called the **nucleus**. They calculated the nucleus to have a positive charge of 100 ± 20 and a radius of about 10^{-12} cm. The current accepted values are 79 and 10^{-13} cm.
   c. When a alpha particle (positive charge) comes in contact with the positive charged nucleus it is repelled backwards thus accounting for the backwards deflection.
   d. Rutherford proposed that the volume of an atom is mostly empty space.

Atomic Structure

Three primary particles – protons, neutrons, and electrons – make up atoms. The model places the protons and neutrons in the very small nucleus, which means the nucleus contains all the positive charge of the atom. Negatively charged electrons surround the nucleus and occupy most of the volume. Atoms have no net charge, so the number of electrons outside the nucleus must equal the number of protons in the nucleus.

Atomic Number and the Mass of an Atom

A. All atoms of an element have the same number of protons in the nucleus. The number of protons and element contains is referred to as its ***atomic number***, generally given the symbol ***Z***. Elements are organized on the period table according to increasing atomic number, or number of protons in the nucleus of the atom.

B. In order to calculate the atomic mass of atoms experiments calculated ratios between the atoms. Because these ratios were cumbersome scientists determined that a standard atom was needed to compare everything else against. The carbon-12 atom with 6 protons and 6 neutrons in the nucleus was assigned a mass value of exactly 12.0000.

1. 1 amu = 1.66054 x 10^{-24} grams = 1/12th the mass of an atom of carbon-12 with 6 protons and 6 neutrons.
2. Protons and neutrons have a mass very close to 1 amu. The electron has a mass that is only 1/2000th the value. Because of this the mass of an atom can be estimated by calculating the number of neutrons and protons.
3. The sum of the protons and neutrons is called the mass number, and is given the symbol A.

C. You can symbolize an atom of known composition by the notation:

$$\begin{matrix} \textit{Atomic Mass} \rightarrow \\ \textit{Atomic Number} \rightarrow \end{matrix} {}^{A}_{Z}X \leftarrow \textit{Element Symbol}$$

1. Subscripts (atomic number) and superscripts (atomic mass) are used to write isotopes of elements.
   Nuclide - specific isotope of an atom.

$^{11}_{6}$**C Nuclide;** $^{12}_{6}$**C Nuclide;** $^{179}_{79}$**Au Nuclide;** $^{39}_{19}$**K Nuclide;** $^{3}_{1}$**H Nuclide;**

2. Calculating protons, neutrons, and electron in a neutral atom.

$$\textit{Atomic number} = \textit{protons and electrons (neutral atom)}$$
$$\textit{Atomic mass} = \textit{atomic number (protons)} + \textit{number of neutrons}$$
$$^{12}_{6}C = 6\ \textit{protons}, 6\ \textit{electrons}, 6\ \textit{neutron}$$

D. There are three subatomic particles that explain the chemical behavior of materials:

Electon	9.109389×10^{-28} *grams*	0.0005485799 *amu*	-1 *charge*	$^{0}_{-1}e$
Proton	1.672623×10^{-24} *grams*	1.007276 *amu*	$+1$ *charge*	$^{1}_{1}P$
Neutron	1.674929×10^{-24} *grams*	1.008665 *amu*	*no charge*	$^{1}_{0}n$

E. Atoms are extremely small; most of them have diameters between 1 x 10^{-10} m and 5 x 10^{-10} m, or 100-500 pm. Another way to express dimensions is the **angstrom** (Å). One angstrom is equal to 10^{-10} m; thus, most atoms have a diameter of 1-5Å.

Isotope

A. **Isotopes** - atoms of the same element but have a different number of neutrons, and consequently different mass. Isotopes are referred to by its mass, hydrogen-1; hydrogen-2; hydrogen-3.

Three Isotope Forms of Hydrogen:

$$(\textit{protium})\ {}^{1}_{1}H\ \ (1\ \textit{proton}, 0\ \textit{neutron})$$
$$(\textit{deuterium})\ {}^{2}_{1}H\ \ (1\ \textit{proton}, 1\ \textit{neutron})$$
$$(\textit{tritium})\ {}^{3}_{1}H\ \ (1\ \textit{proton}, 2\ \textit{neutron})\ \textit{radioactive isotope of hydrogen}$$

B. **Isotope Abundance** - a mass spectrophotometer can be used to obtain accurate masses of an element's isotopes and their percent abundance.

$$\text{Percent Abundance} = \frac{\text{number of atoms of a given isotope}}{\text{total number of atoms of all isotopes of that element}} \text{ x } 100\%$$

Atomic Weight

A. Because a sample of boron contains atoms with different masses the average atomic mass can be calculated. The average mass of a sample of atoms is expressed in atomic mass units, and is called the atomic mass or atomic weight.

B. The average atomic mass can be calculated using the following equation:

$$\text{Average Atomic Mass} = \left(\frac{\%\text{ abundance of isotope 1}}{100}\right)(\text{mass of isotope 1}) + \left(\frac{\%\text{ abundance of isotope 2}}{100}\right)(\text{mass of isotope 2})$$

Current Atomic Theory

When solids are heated, they emit radiation, as seen in the red glow of an electric stove burner. In the late 1800's physicists were studying this phenomenon, trying to understand the relationship between the temperature and the intensity and wavelength of the emitted radiation.

A. Max Planck in 1900 made an assumption:
Energy can be released (or absorbed) by atoms only in "chuncks" of a minimum size.
1. Planck called the smallest amount of energy **quantum**.
2. He proposed that the energy, E, of a single quantum equals a constant times the frequency of the emitted radiation;

$$E = h\nu$$

E = Energy
h = Planck's Constant
ν = Frequency

3. Planck's constant = 6.626×10^{-34} J-s.
4. Energy is always emitted or absorbed in whole-number multiples; hν, 2hν, 3hν, and so forth.
5. Allowed energies are quantized (values are restricted to certain quantities).

B. When dealing with macroscopic objects, such as humans, the gain or loss of a quantum of energy is completely unnoticed. When dealing with microscopic objects, on the atomic level, the impact of quantized energies is far more significant.

C. The Photoelectric Effect.
1. In 1905, Albert Einstein used Planck's quantum theory to explain how light shining on a clean metallic surface causes the surface to emit electrons, this effect is called the photoelectric effect.
2. For each metal there is a minimum frequency of light below which no electrons are emitted.
Example – to remove an electron from a Cs atom it requires frequency of light $4.60 \times 10^{14}\ s^{-1}$ or greater, if the light is lower it will not have an effect.

   a. Einstein assumed that the energy struck the metal in tiny energy packets.
   b. Einstein called his tiny particles of light a **photon**.
   c. If the photon has less energy than the energy threshold of the electron it cannot escape.
   d. If the photon has sufficient energy, the electron is emitted.
   e. If the photon has more than enough energy the excess appears as kinetic energy of the emitted electron.
3. This concept about the energy relationship to frequency helps to explain the difference in behavior between the different kinds of electromagnetic radiation.
4. Einstein's helped proved an answer to one question (photoelectric effect), but left another in its place:

   Is light a wave, or does it consist of particles?
5. Using Planck's Equation:

   Example problem: Compact disc players use lasers that emit red light with a wavelength of 685 nm. What is the energy of one photon of this light? What is the energy of a mole of photons of the light?

$685 \text{ nm} = 685 \times 10^{-9} \text{ m} = 6.85 \times 10^{-7} \text{ m}$

$\nu = c/\lambda = (2.998 \times 10^{8} \text{ m/s}) / (6.85 \times 10^{-7} \text{ m}) = 4.38 \times 10^{14} \text{ s}^{-1}$

$E = h\nu = (6.626 \times 10^{-34} \text{ J-s/photon}) (4.38 \times 10^{14} \text{ s}^{-1}) = 2.90 \times 10^{-19} \text{ J/photon}$

$E = (2.90 \times 10^{-19} \text{ J/photon}) (6.022 \times 10^{23} \text{ photons/mole}) = 1.75 \times 10^{5} \text{ J/mol}$

Atomic Line Spectra and Neils Bohr

A. Line Spectra
1. Sources of light that only emit a single wavelength (laser) are said to be monochromatic.
2. Most light sources produce several wavelengths. When these light sources are separated into their different wavelength components, a spectrum is produced.
3. A prism can disperse "White" light from a light bulb. The spectrum that is produced consists of a continuous range of colors (included all wavelengths).

   Red-Orange-Yellow-Green-Blue-Indigo-Violet
4. Not all radiation produces a continuous spectrum – different gases, when excited, will produce different colors of light (only select wavelengths).
5. In 1885, Johann Balmer (1825 – 1898), and Johannes Rydberg (1854-1919) looking at the frequency of the four spectrum lines of hydrogen fit an intriguingly simple formula:

B. Bohr's Model
1. In 1913, Neil's Bohr proposed that orbits of certain radii (distance) correspond to definite energies.
2. An electron in a permitted orbit has a specific energy state. An electron in an allowed energy state will not radiate energy and therefore will not spiral into the nucleus.
3. The integer ***n***, is called the ***principal quantum number*** and corresponds to the different allowed orbits for the electron.

   n = 1; n = 2; n = 3; n = 4, and so forth
4. n = 1 corresponds to the lowest energy orbit – the one closest to the nucleus of the atom.
5. When the electron is in a lowest state the atom is said to be in its **ground state**.
6. When the electron is in a higher state the atom is said to be in an **excited state**.
7. Electrons can change from one energy state to another by absorbing or emitting radiant energy.
8. The amount of radiant energy absorbed or emitted corresponds exactly to the energy difference between the energy states:

$$Energy\ of\ the\ nth\ level = E_n = -\frac{Rhc}{n^2}$$

R_H = Rydberg constant = $1.0974 \times 10^7\ m^{-1}$

$$\Delta E = E_{final\ state} - E_{initial\ state}$$

$$\Delta E = E_2 - E_1 = \left(-\frac{Rhc}{n^2}\right) - \left(-\frac{Rhc}{n^2}\right)$$

   a. When ΔE is positive when $n_f > n_i$, indicating that radiant energy is absorbed.
   b. When ΔE is negative when $n_f < n_i$, indicating that radiant energy is emitted.

9. Bohr's model was adequate for explaining only atoms and ions with a single electron, such as H, He^+, and Li^{2+}. It could not explain the atomic spectra of other atoms or ions. Bohr's model was eventually replaced by a new way of viewing atoms.

The Wave Properties of the Electron

1. Louis de Broglie (1892 - 1987) made an extension to the wave-particle theory. He wondered if radiant energy could, under appropriate conditions, behave as though it were a stream of particles, could matter under appropriate conditions possibly show the properties of a wave?
   a. De Broglie suggested that the electron in its circular path about the nucleus has associated with it a particular wavelength.
   b. The characteristic wavelength of the electron or of any other particle depends on its mass, m, and velocity, v:

$\lambda = h/mv$

h = Planck's constant
mv = (mass) x (velocity) = momentum

   c. De Broglie called the wave characteristics of material particles ***matter waves***.
   d. Ordinary sized objects have such a small wavelength that it is impossible to observe, but electrons are so small that you can observe their wave properties.
   e. In electron microscopes, the wave characteristics of electrons are used to obtain pictures of small objects.

The Wave Mechanical View of the Atom

1. The Uncertainty Principle
   a. Werner Heisenberg (1901 - 1976) concluded that the dual nature of matter places a fundamental limitation on how precisely we can know both the location and the momentum of any object.
   b. This limitation becomes only important when we deal with matter at the subatomic level, that is, with masses very small, like an electron.
   c. The ***Heisenberg Uncertainty Principle*** states that it is impossible for us to know simultaneously both the exact momentum of the electron and its exact location space.

De Broglie's hypothesis and Heisenberg's uncertainty principle set the stage for a new and more broadly applicable theory of atomic structure.

In 1926, Erwin Schrodinger (1887 - 1961) proposed his wave equation, that incorporates both the wavelike and particlelike behavior of the electron. He opened the door for the new studying subatomic particles, known as ***quantum mechanics*** or ***wave mechanics.***

2. Schrodinger's equation leads to a series of mathematical functions that are represented by the symbol Ψ (the Greek lowercase letter *psi*).
   a. Ψ^2 provides information about an electron's location when it is in an allowed energy state.
   b. The Bohr model of the atom assumes that an electron is in a circular orbit of some particular radius around the nucleus. In the quantum-mechanical model, we cannot specify the location of an individual atom around the nucleus.
   c. In the quantum-mechanical model, we therefore speak of the probability that the electron around the nucleus. Ψ^2 represents the probability that the electron will be found at any one given point in space.

      Ψ^2 *is called the* ***probability density***
   d. Electron density is another way of expressing probability. Regions with a high density of dots correspond to relatively large values for Ψ^2.

Orbitals and Quantum Numbers

a. The complete solution for the Schrodinger's equation yields a set of wave functions and a corresponding set of energies. These wave function are called **orbitals.**
b. An orbital therefore has both a characteristic energy and a characteristic shape.
c. The Bohr atoms introduced a single quantum number, n, to describe an orbit. The quantum-mechanical model uses three quantum numbers, n, ℓ, and m_ℓ, to describe an orbital.
   1. n, the principal quantum number, can have integral values of 1, 2, 3, and so forth. As n increases, the orbital becomes larger, and the electron spends more time farther from the nucleus. An increase in n also means that the electron has a higher energy and is therefore less tightly bound to the nucleus.
   2. ℓ, azimuthal quantum number, can have integral values from 0 to n - 1 for each value of n. This quantum number describes the shape of the orbital. The value of ℓ for a particular orbital is generally designed by the letters, *s*, *p*, *d*, and *f* (sharp, principal, diffuse, and fundamental), corresponding to ℓ values of 0, 1, 2, and 3 respectively.
   3. m_ℓ, magnetic quantum number, can have integral values between $+\ell$ and $-\ell$ including zero. The quantum number describes the orientation of the orbital in space.
d. A collection of orbitals with the same value of n is called an ***electron shell.***
e. One or more orbital with the same set of n and ℓ values is called a ***subshell.***
   1. Each subshell is designated by a number (the value of n) and a letter (*s*, *p*, *d*, or *f*, corresponding to the value of ℓ).
   2. An orbital with a value of $n = 3$ and $\ell = 1$ are collectively called 3*p*.
   3. Relationship Among Values of n, ℓ, and m_ℓ through $n = 4$:

n	ℓ	*Subshell Designation*	m_ℓ	*Number of orbitals in subshell*
1	0	1*s*	0	1
2	0	2*s*	0	1
	1	2*p*	1, 0, -1	3

3	0	3*s*	0	1
	1	3*p*	1, 0, -1	3
	2	3*d*	2, 1, 0, -1, -2	5
4	0	4*s*	0	1
	1	4*p*	1, 0, -1	3
	2	4*d*	2, 1, 0, -1, -2	5
	3	4*f*	3, 2, 1, 0, -1, -2, -3	7

f. The restrictions on the possible values of the quantum numbers give rise to a pattern that is very important;
   1. Each shell is divided into the number of subshells equal to the principal quantum number, n, for that shell.
   2. Each subshell is divided into orbitals. Each ***s*** subshell consists of one orbital; each ***p*** subshell consists of three orbitals; each ***d*** subshell consists of five orbitals; each ***f*** subshell consists of seven orbitals.

The Shapes Of Atomic Orbitals

A. The ***s*** Orbitals
   1. All *s* orbitals are spherically symmetric.
   2. The lowest-energy (most stable) orbital, the 1s orbital.
   3. When the probability function, , for the 1*s* orbital is graphed as a function of the distance from the nucleus, r, it rapidly approaches zero. This effect indicates that the electron, which is drawn toward the nucleus by electrostatic attraction, is unlikely ever to get far from the nucleus.
   4. When the probability function, Ψ^2, for the 2*s* orbital is graphed, Ψ^2 goes to zero and then increases again in value before finally approaching zero at a larger value of r.
   5. The intermediate regions where Ψ^2 goes to zero are called **nodes**.
   6. The number of nodes increases with the increasing value of the principal quantum number, n.
   7. The most widely used method of representing orbitals is to display a boundary surface that encloses some substantial fraction, say 90 percent, of the total electron density for the orbital. For the s orbitals, these contour representations are merely spheres.

B. The ***p*** Orbitals
   1. The electron density for a 2*p* orbital is concentrated on two sides of the nucleus, separated by a node at the nucleus; we often say that this orbital has two lobes.
   2. Each shell beginning with *n* = 2 has three *p* orbitals. These orbitals are labeled $2p_x$, $2p_y$, and $2p_z$ orbitals.
      Note – there is no connection between one of these subscripts and a particular value of m_ℓ.
   3. Like the *s* orbitals, *p* orbitals increase in size as we move from 2p to 3p to 4p, and so forth.

C. The ***d*** Orbitals
   1. In the third shell and beyond, we encounter the *d* orbitals.
   2. There are 5 *d* orbitals, the different *d* orbitals in a given shell have different orientations in space.
   3. Four of the *d* orbitals have four lobes centered around the nucleus in different planes.
   4. One of the *d* orbitals is unique in shape, and has two lobes along the z axis and a "doughnut" in the xy plane. This orbital looks different but has the same energy as the other four *d* orbitals.

5. Like the *s* and *p* orbitals the *d* orbitals increase in size as you move to higher n values.

D. The *f* Orbitals

1. For each value of n of 4 or greater we us the *f* orbitals.
2. There are seven *f* orbitals (for which $\ell = 3$) for each value of n.
3. The f orbitals are difficult to represent in three-dimensional contour diagrams.
4. We will not concern ourselves with orbitals having values for l greater than 3.

Isotope Calculations:

Isotopes Calculations based upon C-12.000

Elements Name - Symbol - Atomic Number			Number of Isotopes	Isotopes	Atomic Mass (C-12 standard)	Percent Abundance	Average Atomic Mass
1	Hydrogen	H	2	^{1}H	1.007825000	99.9850	1.007673826
				^{2}H	2.014100000	0.0150	0.000302115
						100.0000	**1.007975941**
2	Helium	He	2	^{3}He	3.016029309	0.0001	4.13196E-06
				^{4}He	4.002603250	99.9999	4.002597766
						100.0000	**4.002601898**
3	Lithium	Li	2	^{6}Li	6.015122000	7.5000	0.45113415
				^{7}Li	7.016004000	92.5000	6.4898037
						100.0000	**6.94093785**
4	Beryllium	Be	1	^{9}Be	9.012182200	100.0000	**9.0121822**
5	Boron	B	2	^{10}B	10.012937100	19.9000	1.992574483
				^{11}B	11.009305500	80.1000	8.818453706
						100.0000	**10.81102819**
6	Carbon	C	2	^{12}C	12.000000000	98.9000	11.868
				^{13}C	13.003354840	1.1000	0.143036903
						100.0000	**12.0110369**
7	Nitrogen	N	2	^{14}N	14.003074007	99.6300	13.95126263
				^{15}N	15.000108970	0.3700	0.055500403
						100.0000	**14.00676304**
8	Oxygen	O	3	^{16}O	15.994914622	99.7600	15.95652683
				^{17}O	16.999131500	0.0400	0.006799653
				^{18}O	17.999160000	0.2000	0.03599832
						100.0000	**15.9993248**
9	Fluorine	F	1	^{19}F	18.998403300	100.0000	**18.9984033**
10	Neon	Ne	3	^{20}Ne	19.992401760	90.4800	18.08912511
				^{21}Ne	20.993846740	0.2700	0.056683386
				^{22}Ne	21.991385500	9.2500	2.034203159
						100.0000	**20.18001166**
11	Sodium	Na	1	^{23}Na	22.989769700	100.0000	**22.9897697**
12	Magnesium	Mg	3	^{24}Mg	23.985041900	78.9900	18.9457846

				^{25}Mg	24.985837000	10.0000	2.4985837
				^{26}Mg	25.982593000	11.0100	2.860683489
						100.0000	**24.30505179**
13	Aluminium	Al	1	^{27}Al	26.981538400	100.0000	**26.9815384**
14	Silicon	Si	3	^{28}Si	27.976926500	92.2300	25.80311931
				^{29}Si	28.976494700	4.6700	1.353202302
				^{30}Si	29.973770200	3.1000	0.929186876
						100.0000	**28.08550849**
15	Phosphorus	P	1	^{31}P	30.973761500	100.0000	**30.9737615**
16	Sulfur	S	4	^{32}S	31.972070700	95.0200	30.37986158
				^{33}S	32.971458500	0.7500	0.247285939
				^{34}S	33.967866900	4.2100	1.430047196
				^{36}S	35.967080900	0.0200	0.007193416
						100.0000	**32.06438813**
17	Chlorine	Cl		^{35}Cl	34.968852700	75.7700	26.49589969
				^{37}Cl	36.965902650	24.2300	8.956838212
						100.0000	**35.4527379**
18	Argon	Ar		^{36}Ar	35.967546200	0.3370	0.121210631
				^{38}Ar	37.962732200	0.0630	0.023916521
				^{40}Ar	39.962383120	99.6000	39.80253359
						100.0000	**39.94766074**
19	Potassium	K		^{39}K	38.963706900	93.2581	36.33681274
				^{40}K	0.000000001	0.0117	1.4859E-13
				^{41}K	40.961826000	6.7302	2.756812813
						100.0000	**39.09362556**
20	Calcium	Ca		^{40}Ca	39.962591200	96.9410	38.74013554
				^{42}Ca	41.958618300	0.6470	0.27147226
				^{43}Ca	42.958767000	0.1350	0.057994335
				^{44}Ca	43.955481000	2.0860	0.916911334
				^{46}Ca	45.953693000	0.0040	0.001838148
				^{48}Ca	47.952533000	0.1870	0.089671237
						100.0000	**40.07802285**
21	Scandium	Sc		^{45}Sc	44.955910000	100.0000	**44.95591**
22	Titanium	Ti		^{46}Ti	45.952629000	8.2500	3.791091893
				^{47}Ti	46.951764000	7.4400	3.493211242
				^{48}Ti	47.947947000	73.7200	35.34722653
				^{49}Ti	48.947871000	5.4100	2.648079821
				^{50}Ti	49.944792000	5.1800	2.587140226
						100.0000	**47.86674971**

23	Vanadium	V	^{50}V	49.947163000	0.2500	0.124867908
			^{51}V	59.943964000	99.7500	59.79410409
					100.0000	**59.918972**
24	Chromium	Cr	^{50}Cr	49.946049000	4.3500	2.172653132
			^{52}Cr	51.940512000	83.7900	43.520955
			^{53}Cr	52.940653000	9.5000	5.029362035
			^{54}Cr	53.938885000	2.3600	1.272957686
					100.0000	**51.99592786**
25	Manganese	Mn	^{55}Mn	54.938049000	100.0000	**54.938049**
26	Iron	Fe	^{54}Fe	53.939613000	5.8500	3.155467361
			^{56}Fe	55.934941000	91.7500	51.32030837
			^{57}Fe	56.935398000	2.1200	1.207030438
			^{58}Fe	57.933280000	0.2800	0.162213184
					100.0000	**55.84501935**
27	Cobalt	Co	^{59}Co	58.933200000	100.0000	**58.9332**
28	Nickel	Ni	^{58}Ni	57.935348000	68.0800	39.44238492
			^{60}Ni	59.930790000	26.2200	15.71385314
			^{61}Ni	60.931060000	1.1400	0.694614084
			^{62}Ni	61.928348000	3.6300	2.247999032
			^{64}Ni	63.927969000	0.9300	0.594530112
					100.0000	**58.69338128**
29	Copper	Cu	^{63}Cu	62.929601000	69.1700	43.52840501
			^{65}Cu	64.927794000	30.8300	20.01723889
					100.0000	**63.5456439**
30	Zinc	Zn	^{64}Zn	63.929146000	48.6000	31.06956496
			^{66}Zn	65.926036000	27.9000	18.39336404
			^{67}Zn	66.927131000	4.1000	2.744012371
			^{68}Zn	67.924847000	18.8000	12.76987124
			^{70}Zn	69.925325000	0.6000	0.41955195
					100.0000	**65.39636456**
31	Gallium	Ga	^{69}Ga	68.925589000	60.1100	41.43117155
			^{71}Ga	70.924707000	39.8900	28.29186562
					100.0000	**69.72303717**
32	Germanium	Ge	^{70}Ge	69.924249000	21.2300	14.84491806
			^{72}Ge	71.922076000	27.6600	19.89364622
			^{73}Ge	72.923460000	7.7300	5.636983458
			^{74}Ge	73.921178000	35.9400	26.56727137
			^{76}Ge	75.921403000	7.4400	5.648552383
					100.0000	**72.5913715**

33	Arsenic	As	^{75}As	74.921597000	100.0000	**74.921597**
34	Selenium	Se	^{74}Se	73.922474000	0.8900	0.657910019
			^{76}Se	75.919214000	9.3600	7.10603843
			^{77}Se	76.919912000	7.6300	5.868989286
			^{78}Se	77.917304000	23.7800	18.52873489
			^{80}Se	79.916522000	49.6100	39.64658656
			^{82}Se	81.916700000	8.7300	7.15132791
					100.0000	**78.9595871**
35	Bromine	Br	^{79}Br	78.918338000	50.6900	40.00370553
			^{81}Br	80.916290000	49.3100	39.8998226
					100.0000	**79.90352813**
36	Krypton	Kr	^{78}Kr	77.920390000	0.3500	0.272721365
			^{80}Kr	79.916379000	2.2500	1.798118528
			^{82}Kr	81.913485000	11.6000	9.50196426
			^{83}Kr	82.914137000	11.5000	9.535125755
			^{84}Kr	83.911508000	57.0000	47.82955956
			^{86}Kr	85.910615000	17.3000	14.8625364
					100.0000	**83.80002586**
37	Rubidium	Rb	^{85}Rb	84.911792000	72.1600	61.27234911
			^{87}Rb	86.909186000	27.8400	24.19551738
					100.0000	**85.46786649**
38	Strontium	Sr	^{84}Sr	83.913426000	0.5600	0.469915186
			^{86}Sr	85.909265000	9.8600	8.470653529
			^{87}Sr	86.908882000	7.0000	6.08362174
			^{88}Sr	87.905617000	82.5800	72.59245852
					100.0000	**87.61664897**
39	Yttrium	Y	^{89}Y	88.905849000	100.0000	**88.905849**
40	Zirconium	Zr	^{90}Zr	89.904702000	51.4500	46.25596918
			^{91}Zr	90.905643000	11.2200	10.19961314
			^{92}Zr	91.905038000	17.1500	15.76171402
			^{94}Zr	93.906314000	17.3800	16.32091737
			^{96}Zr	95.908275000	2.8000	2.6854317
					100.0000	**91.22364541**
41	Niobium	Nb	^{93}Nb	92.906376000	100.0000	**92.906376**
42	Molybdenum	Mo	^{92}Mo	91.906810000	14.8400	13.6389706
			^{94}Mo	93.905087000	9.2500	8.686220548
			^{95}Mo	94.905841000	15.9200	15.10900989
			^{96}Mo	95.904678000	16.6800	15.99690029
			^{97}Mo	96.906020000	9.5500	9.25452491

			^{98}Mo	97.905407000	24.1300	23.62457471
			^{100}Mo	99.907480000	9.6300	9.621090324
					100.0000	**95.93129127**
43	Technetium	Tc	Tc	None		
44	Ruthenium	Ru	^{96}Ru	95.907600000	5.5200	5.29409952
			^{98}Ru	97.905290000	1.8800	1.840619452
			^{99}Ru	98.905939000	12.7000	12.56105425
			^{100}Ru	99.904219000	12.6000	12.58793159
			^{101}Ru	100.905581000	17.0000	17.15394877
			^{102}Ru	101.904349000	31.6000	32.20177428
			^{104}Ru	103.905429000	18.7000	19.43031522
					100.0000	**101.0697431**
45	Rhodium	Rh	^{103}Rh	102.905504000	100.0000	**102.905504**
46	Palladium	Pd	^{102}Pd	101.905607000	1.0200	1.039437191
			^{104}Pd	103.904034000	11.1400	11.57490939
			^{105}Pd	104.905083000	22.3300	23.42530503
			^{106}Pd	105.903484000	27.3300	28.94342218
			^{108}Pd	107.903895000	26.4600	28.55137062
			^{110}Pd	109.905150000	11.7200	12.88088358
					100.0000	**106.415328**
47	Silver	Ag	^{107}Ag	106.905090000	51.8390	55.41852961
			^{109}Ag	108.904756000	48.1610	52.44961954
					100.0000	**107.8681491**
48	Cadmium	Cd	^{106}Cd	105.906460000	1.2500	1.32383075
			^{108}Cd	107.904180000	0.8900	0.960347202
			^{110}Cd	109.903006000	12.4900	13.72688545
			^{111}Cd	110.904182000	12.8000	14.1957353
			^{112}Cd	111.902758000	24.1300	27.00213551
			^{113}Cd	112.904402000	12.2200	13.79691792
			^{114}Cd	113.903359000	28.7300	32.72443504
			^{116}Cd	115.904756000	7.4900	8.681266224
					100.0000	**112.4115534**
49	Indium	In	^{113}In	112.904062000	4.2900	4.84358426
			^{115}In	114.903879000	95.7100	109.9745026
					100.0000	**114.8180869**
50	Tin	Sn	^{112}Sn	111.904820000	0.9700	1.085476754
			^{114}Sn	113.902782000	0.6500	0.740368083
			^{115}Sn	114.903347000	0.3400	0.39067138
			^{116}Sn	115.901745000	14.5400	16.85211372
			^{117}Sn	116.902955000	7.6800	8.978146944
			^{118}Sn	117.901608000	24.2200	28.55576946

			^{119}Sn	118.903311000	8.5900	10.21379441
			^{120}Sn	119.902198000	32.5900	39.07612633
			^{122}Sn	121.903441000	4.6300	5.644129318
			^{124}Sn	123.905276000	5.7900	7.17411548
					100.0000	**118.7107119**
51	Antimony	Sb	^{121}Sb	120.903822000	57.3000	69.27789001
			^{123}Sb	122.904215000	42.7000	52.48009981
					100.0000	**121.7579898**
52	Tellurium	Te	^{120}Te	119.904060000	0.0960	0.115107898
			^{122}Te	121.903560000	2.6000	3.16949256
			^{123}Te	122.904371000	0.9080	1.115971689
			^{124}Te	123.902819000	4.8160	5.967159763
			^{125}Te	124.904424000	7.1400	8.918175874
			^{126}Te	125.903305000	18.9500	23.8586763
			^{128}Te	127.904461000	31.6900	40.53292369
			^{130}Te	129.906229000	33.8000	43.9083054
					100.0000	**127.5858132**
53	Iodine	I	^{127}I	126.904468000	100.0000	**126.904468**
54	Xeon	Xe	^{124}Xe	123.905889500	0.1000	0.12390589
			^{126}Xe	125.904268000	0.0900	0.113313841
			^{128}Xe	127.903531000	1.9100	2.442957442
			^{129}Xe	128.904778000	26.4000	34.03086139
			^{130}Xe	129.903509000	4.1000	5.326043869
			^{131}Xe	130.905083000	21.2000	27.7518776
			^{132}Xe	131.904155000	26.9000	35.4822177
			^{134}Xe	133.905395000	10.4000	13.92616108
			^{136}Xe	135.907220000	8.9000	12.09574258
					100.0000	**131.2930814**
55	Cesium	Cs	^{133}Cs	132.905447000	100.0000	**132.905447**
56	Barium	Ba	^{130}Ba	129.906311000	0.1060	0.13770069
			^{132}Ba	131.905056000	0.1010	0.133224107
			^{134}Ba	133.904504000	2.4200	3.240488997
			^{135}Ba	134.905684000	6.5930	8.894331746
			^{136}Ba	135.904571000	7.8500	10.66850882
			^{137}Ba	136.905822000	11.2300	15.37452381
			^{138}Ba	137.905242000	71.7000	98.87805851
					100.0000	**137.3268367**
57	Lanthanum	La	^{138}La	137.907110000	0.0900	0.124116399
			^{139}La	138.906349000	99.9100	138.7813333
					100.0000	**138.9054497**
58	Cerium	Ce	^{136}Ce	135.907140000	0.1900	0.258223566

			^{138}Ce	138.905990000	0.2500	0.347264975
			^{140}Ce	139.905435000	88.4800	123.7883289
			^{142}Ce	141.909241000	11.0800	15.7235439
					100.0000	**140.1173613**
59	Praseodymium	Pr	^{141}Pr	140.907628000	100.0000	**140.907628**
60	Neodymium	Nd	^{142}Nd	141.907719000	27.1300	38.49956416
			^{143}Nd	142.909810000	12.1800	17.40641486
			^{144}Nd	143.900830000	23.8000	34.24839754
			^{145}Nd	144.912569000	8.3000	12.02774323
			^{146}Nd	145.913113000	17.1900	25.08246412
			^{148}Nd	147.916889000	5.7600	8.520012806
			^{150N}d	149.920887000	5.6400	8.455538027
					100.0000	**144.2401347**
61	Promethium		Pm	None		**#VALUE!**
62	Samarium	Sm	^{144}Sm	143.911996000	3.1000	4.461271876
			^{147}Sm	146.914894000	15.0000	22.0372341
			^{148}Sm	147.914818000	11.3000	16.71437443
			^{149}Sm	148.917180000	13.8000	20.55057084
			^{150}Sm	149.917272000	7.4000	11.09387813
			^{152}Sm	151.919729000	26.7000	40.56256764
			^{154}Sm	153.922206000	22.7000	34.94034076
					100.0000	**150.3602378**
63	Europium	Eu	^{151}Eu	150.919846000	47.8000	72.13968639
			^{153}Eu	152.921226000	52.2000	79.82487997
					100.0000	**151.9645664**
64	Gadolinium	Gd	^{152}Gd	151.919789000	0.2000	0.303839578
			^{154}Gd	153.920862000	2.1800	3.355474792
			^{155}Gd	154.922619000	14.8000	22.92854761
			^{156}Gd	155.922120000	20.4700	31.91725796
			^{157}Gd	156.923957000	15.6500	24.55859927
			^{158}Gd	157.924101000	24.8400	39.22834669
			^{160}Gd	159.927051000	21.8600	34.96005335
					100.0000	**157.2521193**
65	Terbium	Tb	^{159}Tb	158.925343000	100.0000	**158.925343**
66	Dysprosium	Dy	^{156}Dy	155.924280000	0.0600	0.093554568
			^{158}Dy	157.924405000	0.1000	0.157924405
			^{160}Dy	159.925194000	2.3400	3.74224954
			^{161}Dy	160.902693000	18.9000	30.41060898
			^{162}Dy	161.926795000	25.5000	41.29133273
			^{163}Dy	162.928728000	24.9000	40.56925327
			^{164}Dy	163.929171000	28.2000	46.22802622

					100.0000	**162.4929497**
67	Holmium	Ho	^{165}Ho	164.930319000	100.0000	**164.930319**
68	Erbium	Er	^{162}Er	161.918775000	0.1400	0.226686285
			^{164}Er	163.929197000	1.6100	2.639260072
			^{166}Er	165.930290000	33.6000	55.75257744
			^{167}Er	166.932042000	22.9500	38.31090364
			^{168}Er	167.933236800	26.8000	45.00610746
			^{170}Er	169.935461000	14.9000	25.32038369
					100.0000	**167.2559186**
69	Thulium	Tm	^{159}Tm	158.925343000	100.0000	**158.925343**
70	Ytterbium	Yb	^{168}Yb	167.933895000	0.1300	0.218314064
			^{170}Yb	169.934758000	3.0500	5.183010119
			^{171}Yb	170.936323000	14.3000	24.44389419
			^{172}Yb	171.936378000	21.9000	37.65406678
			^{173}Yb	172.938207000	16.1200	27.87763897
			^{174}Yb	173.938858000	31.8000	55.31255684
			^{176}Yb	175.942569000	12.7000	22.34470626
					100.0000	**173.0341872**
71	Lutetium	Lu	^{175}Lu	174.940768000	97.4100	170.4098021
			^{176}Lu	175.942683000	2.5900	4.55691549
					100.0000	**174.9667176**
72	Hafnium	Hf	^{174}Hf	173.940042000	0.1620	0.281782868
			^{176}Hf	175.940403000	5.2060	9.15945738
			^{177}Hf	176.943220000	18.6060	32.92205551
			^{178}Hf	177.943698000	27.2970	48.57329124
			^{179}Hf	178.945815000	13.6290	24.38852513
			^{180}Hf	179.946549000	35.1000	63.1612387
					100.0000	**178.4863508**
73	Tantalum	Ta	^{180}Ta	179.947466000	0.0120	0.021593696
			^{181}Ta	180.947996000	99.9880	180.9262822
					100.0000	**180.9478759**
74	Tungsten	W	^{180}W	179.946706000	0.1200	0.215936047
			^{182}W	181.948205000	26.4980	48.21263536
			^{183}W	182.950224000	14.3140	26.18749506
			^{184}W	183.950932000	30.6420	56.36624458
			^{186}W	185.954362000	28.4260	52.85938694
					100.0000	**183.841698**
75	Rhenium	Re	^{185}Re	184.952955000	37.4000	69.17240517
			^{187}Re	186.955750000	62.6000	117.0342995
					100.0000	**186.2067047**

76	Osmium	Os	^{184}Os	183.952491000	0.0200	0.036790498
			^{186}Os	185.953838000	1.5800	2.93807064
			^{187}Os	186.955748000	1.6000	2.991291968
			^{188}Os	187.955636000	13.3000	24.99809959
			^{189}Os	188.958145000	16.1000	30.42226135
			^{190}Os	189.958445000	26.4000	50.14902948
			^{192}Os	191.961479000	41.0000	78.70420639
					100.0000	**190.2397499**
77	Iridium	Ir	^{191}Ir	190.960591000	37.3000	71.22830044
			^{193}Ir	192.962923000	62.7000	120.9877527
					100.0000	**192.2160532**
78	Platinum	Pt	^{190}Pt	189.959930000	0.0100	0.018995993
			^{192}Pt	191.961035000	0.7900	1.516492177
			^{194}Pt	193.962663000	32.9000	63.81371613
			^{195}Pt	194.964774000	33.8000	65.89809361
			^{196}Pt	195.964934000	25.3000	49.5791283
			^{198}Pt	197.967875000	7.2000	14.253687
					100.0000	**195.0801132**
79	Gold	Au	^{197}Au	196.966551000	100.0000	**196.966551**
80	Mercury	Hg	^{196}Hg	195.965814000	0.1500	0.293948721
			^{198}Hg	197.966752000	9.9700	19.73728517
			^{199}Hg	198.968262000	16.8700	33.5659458
			^{200}Hg	199.968309000	23.1000	46.19267938
			^{201}Hg	200.970285000	13.1800	26.48788356
			^{202}Hg	201.970625000	29.8600	60.30842863
			^{204}Hg	203.973475000	6.8700	14.01297773
					100.0000	**200.599149**
81	Thallium	Ti	^{203}Ti	202.972324000	29.5200	59.91743004
			^{205}Ti	204.974412000	70.4800	144.4659656
					100.0000	**204.3833956**
82	Lead	Pb	^{204}Pb	203.973028000	1.4000	2.855622392
			^{206}Pb	205.974449000	24.1000	49.63984221
			^{207}Pb	206.975880000	22.1000	45.74166948
			^{208}Pb	207.976636000	52.4000	108.9797573
					100.0000	**207.2168913**
83	Bismoth	Bi	^{209}Bi	208.980384000	100.0000	**208.980384**
84	Polonium	Po	Po	None		
85	Astatine	At	At	None		

86	Radon	Rn	Rn	None		
87	Francium	Fr	Fr	None		
88	Radium	Ra	Ra	None		
89	Actinium	Ac	Ae	None		
90	Thorium	Th	^{232}Th	232.038050000	100.0000	**232.03805**
91	Protactinium	Pa	Pa	None		
92	Uranium	U	^{234}U	234.039627000	0.0055	0.012872179
			^{235}U	235.043922000	0.7200	1.692316238
			^{238}U	238.050785000	99.2745	236.3237266
					100.0000	**238.028915**
93	Neptunium	Np	Np	None		
94	Plutonium	Pu	Pu	None		
95	Americium	Am	Am	None		
96	Curium	Cm	Cm	None		
97	Berkelium	Bk	Bk	None		
98	Californium	Cf	Cf	None		
99	Einsteinium	Es	Es	None		
100	Fermium	Fm	Fm	None		
101	Mendelevium	Md	Md	None		
102	Nobelium	No	No	None		
103	Lawrencium	Lr	Lr	None		
104	104	Rf	Rf	None		
105	105	Db	Db	None		
106	106	Sg	Sg	None		
107	107	Bh	Bh	None		
108	108	Hs	Hs	None		

109	109	Mt	Mt	None
110	110	Uun	Uun	None
111	111	Uuu	Uuu	None
112	112	Uub	Uub	None

Class Session #8

Class Focus: The Electronic Configuration and Reorganization of the Table

Group Activities: Group Presentations
Genesis Education: Cosmic Chemistry – An Elementary Question

Weekly Readings: *"Adventures in the Atomic Age*", Seaborg, G. and Seaborg, E. (2001)

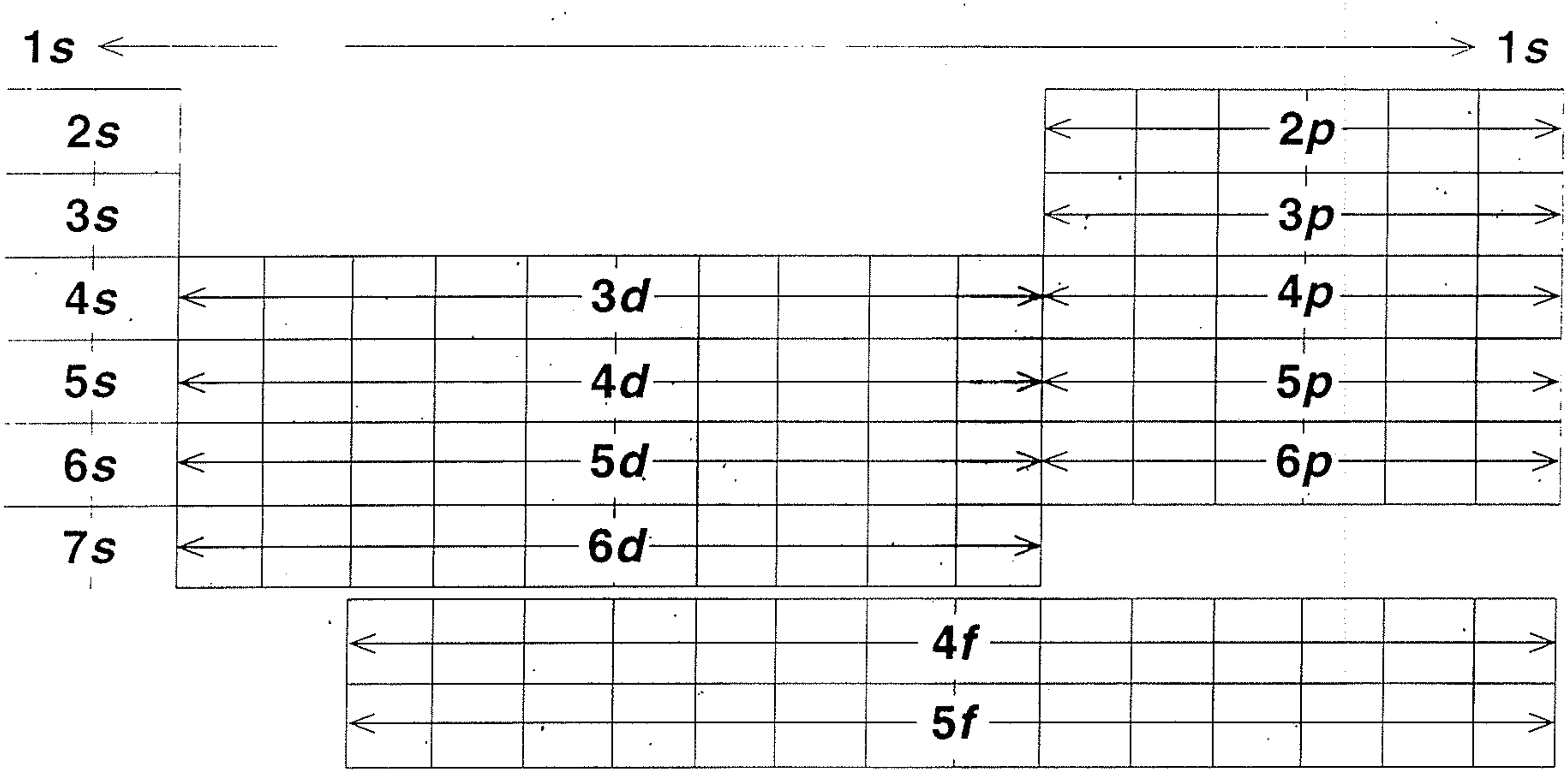
Group Activity: Genesis Education

Have students log on to computers and do the Mendeleev Simulation.

1. Go to - http://genesismission.jpl.nasa.gov/
2. Click, *Classrooms Link*
3. Click, + *Science Modules*
4. Click, *Cosmic Chemistry: An Elemental Question*

Review Introduction Material
1. Click and Print, *Module Overview*
2. Click and Print, *Teacher and Student Guides* for reference.

Activities
1. Atoms, Elements, and Isotopes
2. Calculating Oxygen Isotope Ratios
3. Modeling Oxygen Isotope Ratios
4. Development of a Model: Analyzing Elemental Abundance
5. Development of a Model: Analyzing Elemental Abundances on Earth
6. Connecting Models and Critical Questions



▢ *s*–block elements

▢ *d*–block elements (transition metals)

▢ *p*–block elements

▢ *f*–block elements: lanthanides (4*f*) and actinides (5*f*)

Table 8.4 • Orbital Box Diagrams for the Elements Ca Through Zn

		3d					4s
Ca	$[\mathrm{Ar}]4s^{2}$						↑↓
Sc	$[\mathrm{Ar}]3d^{1}4s^{2}$	↑					↑↓
Ti	$[\mathrm{Ar}]3d^{2}4s^{2}$	↑	↑				↑↓
V	$[\mathrm{Ar}]3d^{3}4s^{2}$	↑	↑	↑			↑↓
Cr*	$[\mathrm{Ar}]3d^{5}4s^{1}$	↑	↑	↑	↑	↑	↑
Mn	$[\mathrm{Ar}]3d^{5}4s^{2}$	↑	↑	↑	↑	↑	↑↓
Fe	$[\mathrm{Ar}]3d^{6}4s^{2}$	↑↓	↑	↑	↑	↑	↑↓
Co	$[\mathrm{Ar}]3d^{7}4s^{2}$	↑↓	↑↓	↑	↑	↑	↑↓
Ni	$[\mathrm{Ar}]3d^{8}4s^{2}$	↑↓	↑↓	↑↓	↑	↑	↑↓
Cu*	$[\mathrm{Ar}]3d^{10}4s^{1}$	↑↓	↑↓	↑↓	↑↓	↑↓	↑
Zn	$[\mathrm{Ar}]3d^{10}4s^{2}$	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓

*These configurations do not follow the "$n + \ell$" rule.

Class Session #9

Class Focus: Glenn Seaborg and the Actinide Series

Group Activities: Group Presentations
Group and Family Association of the Table

Weekly Readings: *"Adventures in the Atomic Age*", Seaborg, G. and Seaborg, E. (2001)

Video: *"Trinity and Beyond - The Atomic Bomb Movie" (1999) by* Goldhil Home Media

Key Notes for Class Session #9

The Elements, Their Chemistry, and The Periodic Table.

A. *Group 1 (1A); The Alkali Metals: Li, Na, K, Rb, Cs, Fr*
   1. The group 1A elements are very reactive. They react with water to produce hydrogen and alkaline solutions.
   2. They are only found in compounds in nature.
   3. Oxide formula - A_2O

   Alkali - comes from the Arabic language; ancient Arabian chemists discovered that ashes of certain plants (al-qali), gave water solutions that felt slippery and burned the skin. These ashes contain compounds of Group 1A elements that produce alkaline solutions.

B. *Group 2 (2A), the Alkaline Earth Metals: Be, Mg, Ca, Sr, Ba, Ra*
   1. Most oxides, (CaO) of this family form, alkaline solutions: hence, they are known as the alkaline earth elements.
   2. Except for Beryllium these metals also react with water.
   3. Magnesium and Calcium are the seventh and fifth most abundant elements in the earth's crust, respectively.
   4. Calcium is especially well known. It is one of the important elements in teeth and bones, and it occurs in vast limestone and of corals, sea shells, marble, and chalk.
   5. Radium, is the heaviest alkaline earth elements and is radioactive, it is used to treat some cancers.
   6. Oxide formula- AO

C. *Group 3 – 12, Transition Elements*
   1. The elements that fill the center part of the table are called the transition elements.
   2. All are elements and 13 of them are in the top 30 in terms of abundance in the earth's crust.
   3. Virtually all of these metals can be found as pure elements in nature and thus are used in a variety of commercial products.
   4. Iron, plays a very important biological role in our bodies. It is the central element in hemoglobin, the oxygen carrying component of blood.
   5. The lanthanides at the bottom of the table (57 - 72) and the actinides (89 - 104) are used in minimal capacities. Uranium is used for nuclear power, and Americium is used in smoke detectors.

D. *Group 13 (3A); B, Al, Ga, In, Tl*
   1. Aluminum, Indium, Gallium, and Thallium are all metals; aluminum is the most abundant metal element in the earth's crust, and the third most over-all abundant.
   2. Boron is a metalloid it is mined in Death Valley, California, and is used for cleaning agents, antiseptics, and flux.
   3. Oxide formula - A_2O_3

E. *Group 14 (4A); C, Si, Ge, Sn, Pb*
   1. This is the only group that contains metals (Pb, Sn), nonmetals (C), and metalloids (Si, Ge).
   2. Carbon is the basis for the great variety of chemical compounds that make up living things.
   3. Carbon, like other nonmetals, can exist in several different and very distinct forms, called allotropes.
   4. Carbon has three allotropes:
      a. Graphite - sheets of interconnected, hexagonal rings. These sheets are held weakly together so that one sheet can slid over another, thus making graphite a good lubricant, and makes it work well in pencils.
      b. Diamond - carbon atoms are arranged in six-sided rings, but the rings are tetrahedron in shape and are not flat. This no flat structure causes diamonds to be very hard, and chemically less reactive than graphite.
         1. *Scientists have discovered a method to grow thin films of diamonds, thus making it possible to coat objects and make their surface very hard.*
         2. *Some scientists believe that this discovery is potentially the greatest advance in material science since the invention of plastic.*

      c. Buckminsterfullerene (Buckyballs) - 60 carbon atoms arranged in a spherical cage structure. Discovered in the 1980s, as stuff that collects when carbon-containing materials are burned in a deficiency of oxygen.
   5. Silicon is the basis of many minerals such as quartz and gemstones. Tin is used with copper to form bronze, which was used for centuries in utensils and weapons. Lead has been used in water pipes and paint. The word "plumbing" comes from the Latin word for lead, plumbum, a name that is also the origin of its symbol, Pb.
   6. Oxide formula - AO_2.

F. *Group 15 (5A); N, P, As, Sb, Bi*
   1. Nitrogen, in the form of N_2, makes up about three-fourths of the earth's atmosphere and accounts for almost all of the nitrogen at the earth's surface. Nitrogen is essential to life in the nitrogen cycle. Nitrogen is the key element in fertilizers.
   2. Phosphorus is also essential to life as an important constituent in bones and teeth. The element glows in the dark if it is in the air, and its name, based on Greek words meaning "light-bearing", reflects this. White Phosphorus and Red Phosphorus are two allotropes. White phosphorus is used to make phosphoric acid used in soda drinks. Red phosphorus is used in the striking strips on match books.
   3. Bismuth is the heaviest element on the periodic table that is not radioactive; all elements above Bi (83) emit radiation.

G. *Group 16 (6A); O, S, Se, Te, Po*
   1. Oxygen constitutes about 20% of earth's atmosphere and which combines readily with most other elements. Most of the energy that powers life on earth is derived from reactions in which oxygen combines with other substances.
   2. Sulfur, selenium, and tellurium are referred to as chalcogens (Greek work, khalkos, for copper), because they are found in copper ores. Sulfuric acid is the most important compound of sulfur; it is manufactured in the largest amount in the chemical industry.

3. Oxygen has a well-known allotrope, ozone, O_3. Sulfur has several allotropic forms.
4. Polonium was isolated by Marie and Pierre Curie in 1898, from tons of uranium ore. It is named after Marie's native country, Poland.

H. *Group 17 (7A); Halogens: F, Cl, Br, I, At*

1. All the 7A elements exist as diatomic molecules. All combine violently with alkali metal to form salts, such as table salt, NaCl. The name of the group Halogens, comes from the Greek words, hals, meaning, "salt", genes, for "formers".
2. They are the most reactive elements known and combine with numerous metals and other nonmetals.

I. *Groups 18 (8A); Noble Gases: He, Ne, Ar, Kr, Xe, Rn*

1. The least reactive of all the elements. All are gases and not very abundant on the earth, thus not discovered until the end of the 19th century. Helium is the second most abundant element in the universe.
2. Until 1962 it was believed that none of these elements would chemically with any other element, but scientists were able to combine xenon with fluorine. This led to the name noble gases, to mean general lack of reactivity. They are sometimes called inert gases or rare gases.
3. Helium is lighter than air and is used in balloons and blimps. Neon and argon is used in advertising signs. Radon is radioactive and toxic and seeps out of the ground into buildings.

Group and Family Association of the Table

Directions: Identify the group to which each transition element belongs. Use numbers 3 through 12 to complete the table. Group 12, although not transition elements by the IUPAC definition, will be included. The lanthanide and actinide series will be excluded.

ELEMENT	GROUP	ELEMENT	GROUP	ELEMENT	GROUP
Bohrium		Manganese		Scandium	
Cadmium		Meitnerium		Seaborgium	
Cobalt		Mercury		Silver	
Copper		Molybdenum		Tantalum	
Chromium		Nickel		Technetium	
Dubnium		Niobium		Titanium	
Gold		Osmium		Tungsten	
Hafnium		Palladium		Vanadium	
Hassium		Platinum		Yttrium	
Iridium		Rhenium		Zinc	
Iron		Rhodium		Zirconium	
Lawrencium		Ruthenium			

Directions: In the chart below, write the names of all the alkaline earth metals, their symbols, and their atomic numbers. Then, in the element puzzle box, highlight the symbols and atomic numbers for all the alkaline earth metals. The highlighted shape will provide you with the answer to this incomplete sentence:

All alkaline earth metals form ions with a ______________ charge.

ELEMENT	SYMBOL	ATOMIC NUMBER

ELEMENT PUZZLE BOX

Bi	Co	18	Sc	Ni	43	82	Rb	Cs	87
Md	24	Be	Mg	Mo	42	41	56	Ge	79
Cu	88	Mn	29	4	Na	6	20	15	84
36	Mo	Fe	Cu	Ca	Ru	Ca	Ra	Ba	Xe
85	Sc	17	As	Ba	77	Tl	88	57	55
52	34	Au	Mg	37	76	Hg	12	10	Ta
Fe	He	Sr	Ag	51	82	19	13	Pb	Re
Hf	4	38	20	Sr	Sb	Co	Ga	Li	Pt
Rn	21	3	Ti	Sn	Pb	Eu	16	34	Pd
22	Ti	5	Zr	Ti	Ta	Sm	40	54	Kr

Group and Family Association of the Table

Directions: Identify the element and the group to which it belongs from the statements and the letter clues.

1. ___ ___ L ___ ___ ___ ___ is used to make chips for computers. Group _____
2. ___ ___ T ___ ___ ___ ___ ___ is an important ingredient used in plant fertilizers. Group _____
3. ___ X ___ ___ ___ ___ is a component of air that is necessary for life. Group _____
4. B ___ ___ ___ ___ is extracted from borax and is used in fire retardants and detergents. Group _____
5. ___ ___ ___ ___ ___ ___ Y is a liquid metal used in barometers. Group _____
6. ___ ___ L L ___ ___ ___ is used in microwave equipment. Group _____
7. When an automobile is not properly in tune, it will not burn the fuel properly, causing ___ ___ R ___ ___ ___ deposits to build up on the engine. Group _____
8. ___ ___ ___ F ___ ___ is a yellow nonmetal that smells of rotten eggs when burnt. Group _____
9. ___ ___ ___ M ___ ___ ___ ___ soda cans are easily crushed. Group _____
10. When combined with copper, ___ ___ ___ C forms the alloy brass. Group _____
11. This element is abundant in the soil, and is an effective poison. A famous play was titled ___ R S ___ ___ ___ ___ *and Old Lace.* Group _____
12. ___ E ___ ___ N ___ ___ ___ is used in photoelectric and solar cells. Group _____
13. ___ ___ D M ___ ___ ___ is used in rechargeable batteries, but is toxic. Group _____
14. Some foods are canned commercially in ___ I ___ cans. The inside of these cans is coated with a protective finish to prevent corrosion. Group _____
15. P ___ ___ ___ N ___ ___ ___ is a radioactive element named after Poland. Group _____
16. ___ ___ ___ M ___ ___ H is found in pharmaceuticals and cosmetics. Group _____
17. The white form of ___ ___ ___ ___ P ___ ___ ___ ___ S is highly flammable. Group _____
18. Diamonds are a valuable form of ___ ___ ___ B ___ ___. Group _____
19. The ___ ___ N Man in *The Wizard of Oz* wanted a heart. Group _____
20. ___ N ___ ___ ___ ___ is used in safety devices. Group _____

Group and Family Association of the Table

Directions: Match the names of the seventeen numbered elements with the lettered hints about the source of their names. Write the correct letter on the line next to the element name.

ANSWER	ELEMENT	HINTS
______	1. Americium	(a) American nuclear chemist
______	2. Berkelium	(b) French chemist
______	3. Bohrium	(c) Danish physicist
______	4. Californium	(d) A coveted prize
______	5. Curium	(e) German province
______	6. Dubnium	(f) Eighth planet from the sun
______	7. Einsteinium	(g) The country you are living in
______	8. Fermium	(h) Town in California
______	9. Hassium	(i) Russian city
______	10. Lawrencium	(j) A man's first name
______	11. Meitnerium	(k) Gold-foil experiment
______	12. Mendelevium	(l) West-coast state
______	13. Neptunium	(m) Austrian physicist
______	14. Nobelium	(n) First published periodic table
______	15. Plutonium	(o) Italian nuclear scientist
______	16. Rutherfordium	(p) Developer of the theory of relativity
______	17. Seaborgium	(q) Ninth planet from the sun

Class Session #10

Class Focus: The Current Table and the Issues of IUPAC

Group Activities: Group Presentations
Trends of the Periodic Table

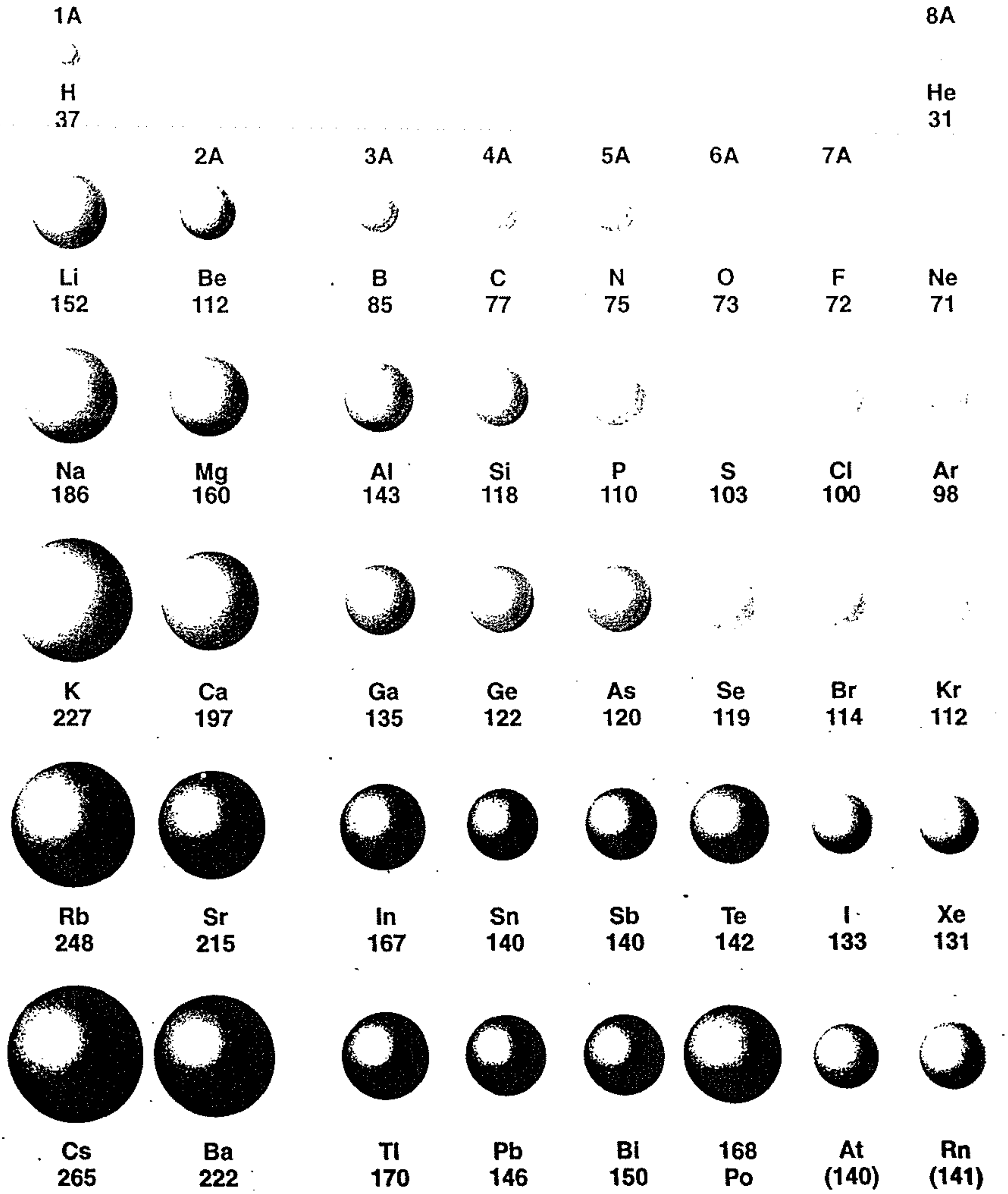
Single Bond Lengths

Group	1A	4A	5A	6A	7A	4A	5A	6A	7A	7A	7A
	H	C	N	O	F	Si	P	S	Cl	Br	I
H	74	110	98	94	92	145	138	132	127	142	161
C		154	147	143	141	194	187	181	176	191	210
N			140	136	134	187	180	174	169	184	203
O				132	130	183	176	170	165	180	199
F					128	181	174	168	163	178	197
Si						234	227	221	216	231	250
P							220	214	209	224	243
S								208	203	218	237
Cl									200	213	232
Br										228	247
I											266

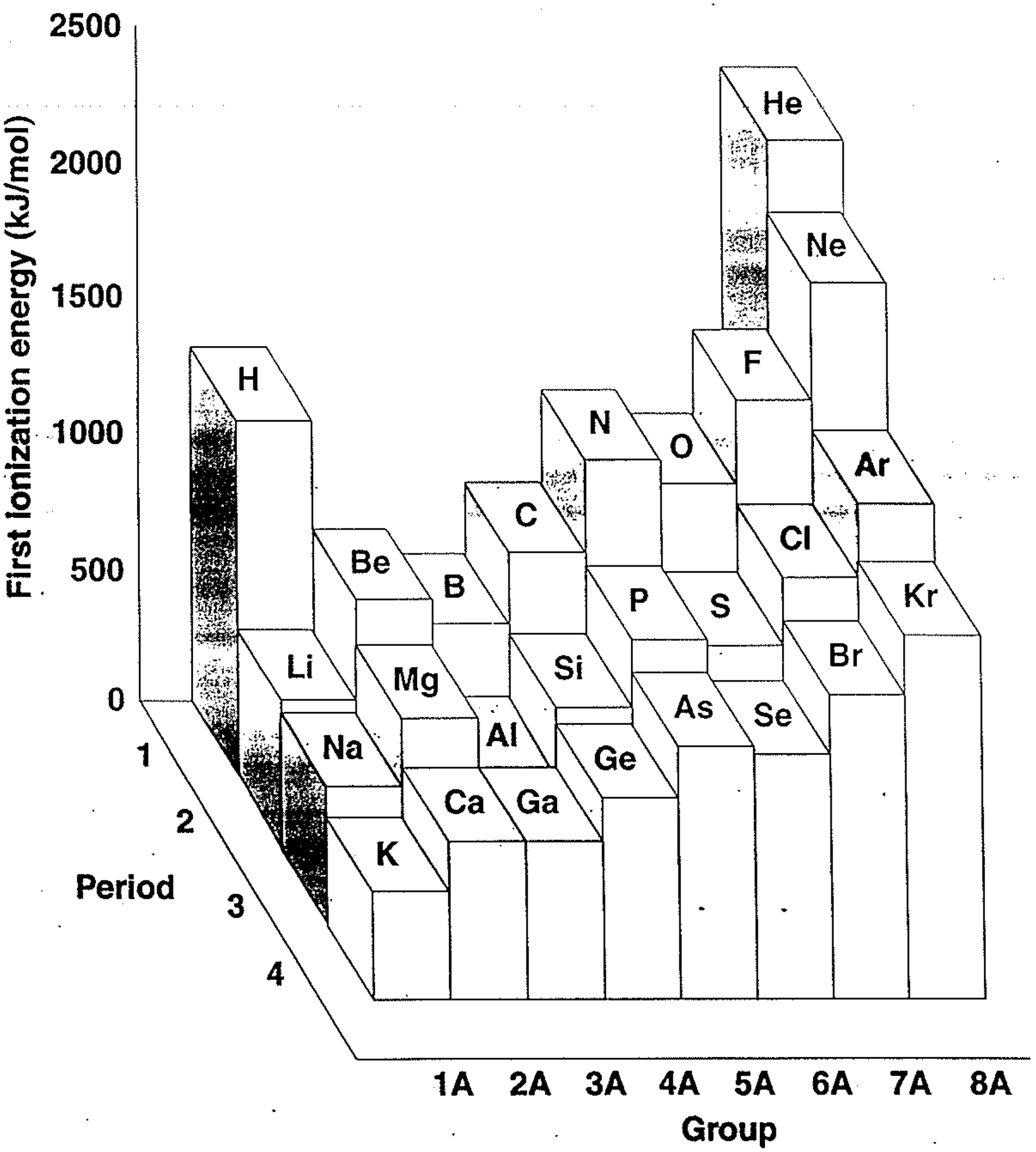
Multiple Bond Lengths

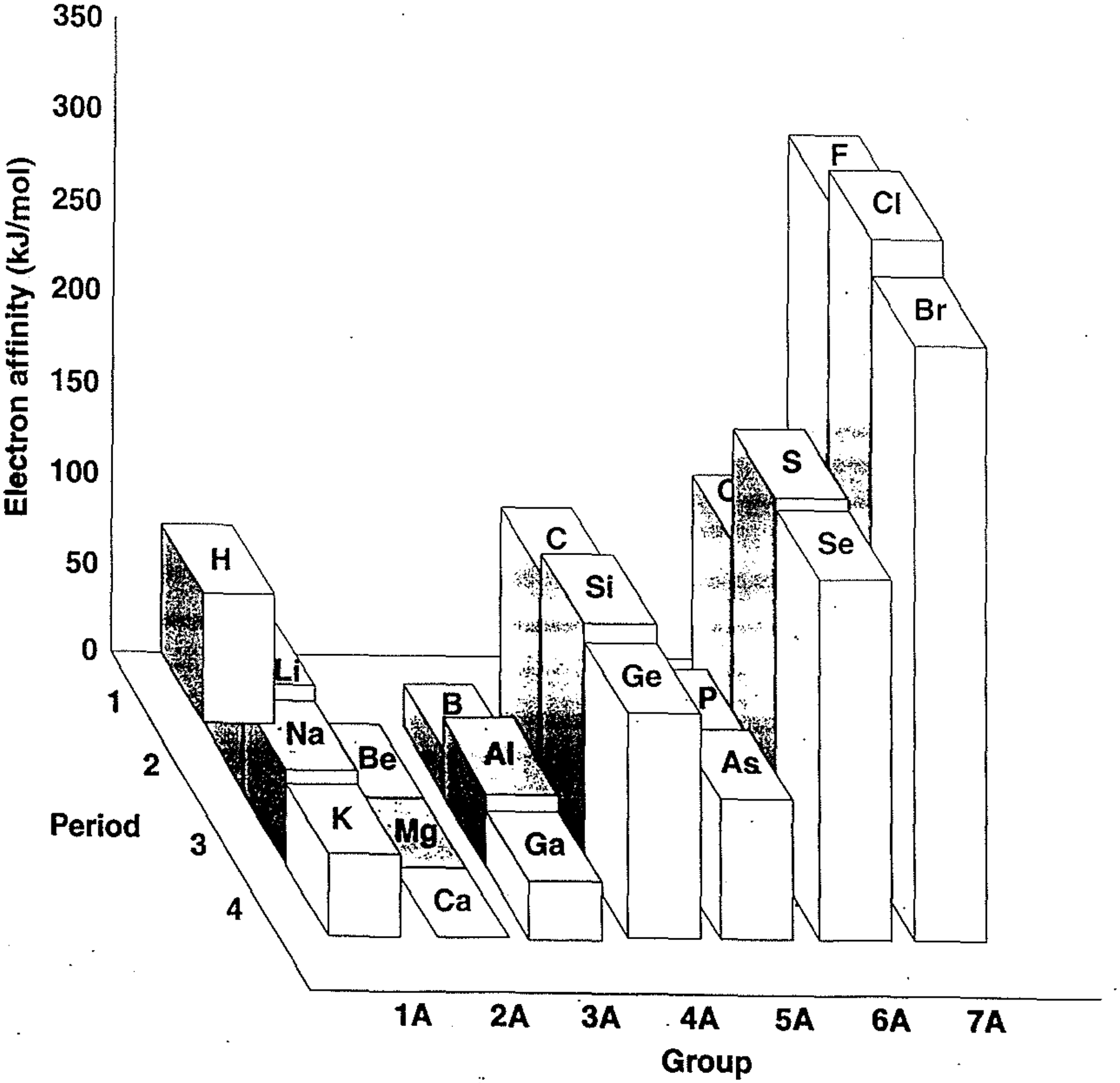
C=C	134	C≡C	121
C=N	127	C≡N	115
C=O	122	C≡O	113
N=O	115	N≡O	108

*In picometers (pm); 1 pm = 10^{-12}m.


1A
8A
H
37
He
31
2A
3A
4A
5A
6A
7A
Li
152
Be
112
B
85
C
77
N
75
O
73
F
72
Ne
71
Na
186
Mg
160
Al
143
Si
118
P
110
S
103
Cl
100
Ar
98
K
227
Ca
197
Ga
135
Ge
122
As
120
Se
119
Br
114
Kr
112
Rb
248
Sr
215
In
167
Sn
140
Sb
140
Te
142
I
133
Xe
131
Cs
265
Ba
222
Tl
170
Pb
146
Bi
150
168
Po
At
(140)
Rn
(141)

Trends of the Periodic Table




350
300
250
200
150
100
50
0
Electron affinity (kJ/mol)
Period
1
2
3
4
H
Li
Na
K
Be
Mg
Ca
B
Al
Ga
C
Si
Ge
O
P
As
S
Se
F
Cl
Br
1A
2A
3A
4A
5A
6A
7A
Group

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CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

When one looks at the periodic table, they should see more than just the elements. They should be able to see the human mind's reflection of the world.

Oliver Sacks (2001) explains his thoughts about first seeing the periodic table:

> I got a sudden, overwhelming sense of how startling the periodic table must have seemed to those who first saw it-chemists profoundly familiar with seven or eight chemical families, but who had never realized the basis of these families (valency), nor how all of them might be brought together into a single overarching scheme. I wondered if they had reacted as I did to this first revelation: "Of course! How obvious! Why didn't I think of it myself?"
>
> Whether one thought in terms of verticals or in terms of the horizontals-either way one arrived at the same grid. It was like a crossword puzzle that could be approached by either the "down" or the "across" clues, except that a crossword was arbitrary, a purely human construct, while the periodic table reflected a deep order in nature, for it showed all the elements arrayed in a fundamental relationship. I had the sense that it harbored a marvelous secret, but it was a cryptogram without a key-why was this relationship so?

> I could scarcely sleep for the excitement the night after seeing the periodic table-it seemed to me an incredible achievement to have brought the whole, vast, and seemingly chaotic universe of chemistry to an all-embracing order…The next day I could hardly wait for the museum to open, and dashed up to the top floor, where the table was, as soon as the doors were opened. (p. 190-191)

It is the excitement that Oliver Sacks had for the periodic table that I hope to pass along to my students and to other teachers. The power behind the periodic table is in the understanding of how the table came to be, once this power has been achieved then the application of this power will seem endless. The table has evolved and will continue to evolve as scientists investigate the universe; as new discoveries are made, as new elements are synthesized, and as new theories are broached. It was my personal goal to learn more about the periodic table and I feel that that goal has been achieved. Regardless of how this project is used in the future I have become a better teacher because of the new knowledge I have gained from this work. I can honestly say that I understand the power of the periodic table and I am looking forward to passing this new knowledge on to others.

Conclusions

The need for professional development courses in science is becoming a necessity in order for districts to continue to align their curriculum with the new state EALR's and GLE's. This course is designed to help teachers gain a better understanding of the periodic table and provide an opportunity to bring new materials into the classroom. This course helps the teachers establish the in-depth knowledge needed to meet the benchmark components and provides them an opportunity to work collaboratively with teachers of similar grade levels. Students of all social and economic backgrounds can benefit from a greater understanding of the periodic table. The hands-on and group-work utilized in the course provides teachers the opportunity to expand upon their constructivist classrooms. A fundamental tool in all science classrooms is the periodic table and providing opportunities for teachers to gain a greater understand of the table will facilitate a greater understanding and appreciation within the minds of our students.

Recommendations

As I was researching the information for this project I constantly found myself latching on to different ideas that I felt would be excellent for further research to develop a greater understanding of the periodic table. My focus was to stay within the scope of taking the visual periodic table up to Mendeleev and then to its current form. This forced me to skip over a lot of information that I felt would be very beneficial to the classroom curriculum. The following is list of recommendation for further research that could enhance all science curriculum courses:

- The discovery and application of the elements of the periodic table. The historical discovery of the elements is a journey through time from the very earliest days of man. Each element has unique properties and applications to real-life situations. Students and teachers research based upon the elements would bring many fascinating stories and applications to the classroom curriculum.
- The loves, lives, and tragedies of scientists are another beneficial application to the periodic table and science classes in general. Students sometimes forget that

these great people had lives outside the laboratory. The stories of these scientists allow the teacher to put a humanistic feel to the great names in science. Stories like; Robert Bunsen losing an eye; H.G.J. Moseley being killed in the war at twenty-six, Antoine Lavoisier life ended in the guillotine; Pierre Curie being run over by horse buggy; Marie Curie's struggles with being accepted because she was a woman; etc. The biographies of scientists provide learning experiences and derive many captivating stories for the classroom environment.

- Investigation into the number of serendipity events that have led to great discoveries in science. Throughout time many scientific discoveries have occurred by accident, these stories of discovery will provide the students pieces of science trivia that would fuel their desire for a greater understanding of our scientific world.
- Students have a fascination with the development of atomic weapons and atomic energy. The development of the bomb, effects of the bomb and the secrecy surrounding it continues to be something the students are interested in. In the last twenty-years more information has become available on the development of the bomb and the effects of nuclear energy. As future tax paying citizens all our students need to understand the principles behind atomic energy and its benefits and hazards.
- The science of today is very interesting, especially the science related to particle accelerators. The synthesis of new elements and the destruction of elements to gain a better understanding of the world around us. Current research and discoveries of elements provide the students an up to date look at the periodic

table and where it is going. These evolving ideas of science helps to develop the scientific minds our students need to support our future. Further researching and keeping up with current changes is vital as our students work out of the schools into college and into these fields of discovery.

- All science teachers should approach their classrooms with a high level of "excitement" for science education. It is this exhilaration of science that will be passed along to the students, encouraging them to look at science as a future profession. Teachers could benefit from further educational research in instructional theory based upon classroom motivation. Teaching science is more than just providing facts and information, it needs to be a passion that is apparent in the way that we teach our students day-to-day.
- Teachers need to be learners for the rest of their lives. Continual professional development is necessary to remain current in the ever changing world of science. Teachers need to also be current in the changes related to best practices in education. The best science teachers are the teachers who are constantly willing to improve and quest for a greater understanding of our physical world and their individual instructional practices.

I like to think that the options for further review and research are endless when looking at the periodic table. The most important aspect to any science classroom is going to be the passion for science that the teacher brings to each lesson. The periodic table is a journey of historical development and atomic discovery. The periodic table will continue to be the cornerstone behind all mankind's knowledge of our physical world and it will continue to drive our desire to learn more.

CHAPTER VI

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