Nitrogen

Jacob F. Valdez, Ritchie Baddour, Dakota Hardi

University of Texas at Tyler

Author Note

Jacob F. Valdez, General Chemistry, UTTyler University

This essay was motivated by Professor Restivo, General Chemistry professor at UTTyler

Correspondence concerning this article should be directed toward: Jacob Valdez, 600 W. Second St., Waxahachie TX, 75165. Or contact: jacobfv@msn.com

Abstract

Nitrogen is an amazing element on the periodic table. This paper will describe what Nitrogen is, the entomology of its name, how it was discovered, where it can be found, how it is isolated, and where it is used along with a general discussion of the element, how it relates to the mole concept, and how it conforms to many periodic trends.

Nitrogen

Nitrogen is a commonly used element on the earth. It composes 78% of the Earth's atmosphere, serves as the primary component of many fertilizers, comprises life giving proteins in humans, and is used to transfer energy in pneumatic systems. As a chemical, it is used in a wide variety of chemical reactions making it a very useful element.

Etymology

The word nitrogen was first reflected in the Greek words "nitron genes" meaning nitre and forming. (Nitrogen) Nitre means Potassium nitrate. (Saltpeter) Nitrogen was further seen in language through the use of the Latin word "nitrum." (Nitrogen) This development of the word for nitrogen is noteworthy considering the sparse knowledge of its properties for much of human history.

Discovery

Since the time of ancient Greece, the universe was thought to have been made out of four fundamental components: earth, water, fire, and air. (Joseph Priestley and the Discovery of Oxygen) This theory remained unchallenged for millennia. (Joseph Priestley and the Discovery of Oxygen) However, the late 18^{th} century saw a rapid increase in the study of air. (Joseph Priestley and the Discovery of Oxygen) It came to be known that the atmosphere consisted not of one but multiple elements. (nitrogen: The Essentials) Two primary components were identified, one of which "supports combustion and life, and the other of which does not." (Nitrogen: The

Essentials) In the year 1774, Joseph Priestly discovered what would later become known as oxygen and found the long sought-after answer as to why things burn. (Joseph Priestley and the Discovery of Oxygen) Oxygen, was found to be a primary component of air. (Joseph Priestley and the Discovery of Oxygen) However, another mysterious element remained in the atmosphere. In 1772, Daniel Rutherford discovered what he called “noxious air.” (Joseph Priestley and the Discovery of Oxygen) He discovered this gas by using potash to absorb all the carbon dioxide out of a container and then observing whether mice could survive in an environment with the remaining air. (Joseph Priestley and the Discovery of Oxygen) Was this new gas discovered the other, dominate, gas in the atmosphere? Scientists may still have continued to wonder such questions for decades. Evidently though, by the year 1807, nitrogen was a commonly accepted element since John Dalton included its symbol in his book *New System of Chemical Philosophy*. (Nitrogen: The Essentials)

Discussion

Today, nitrogen is known to be element number 7, lying at the 15th row, or row VB according to the International Union of Pure and Applied Chemistry, and sitting on the second period of the periodic table. (Periodic

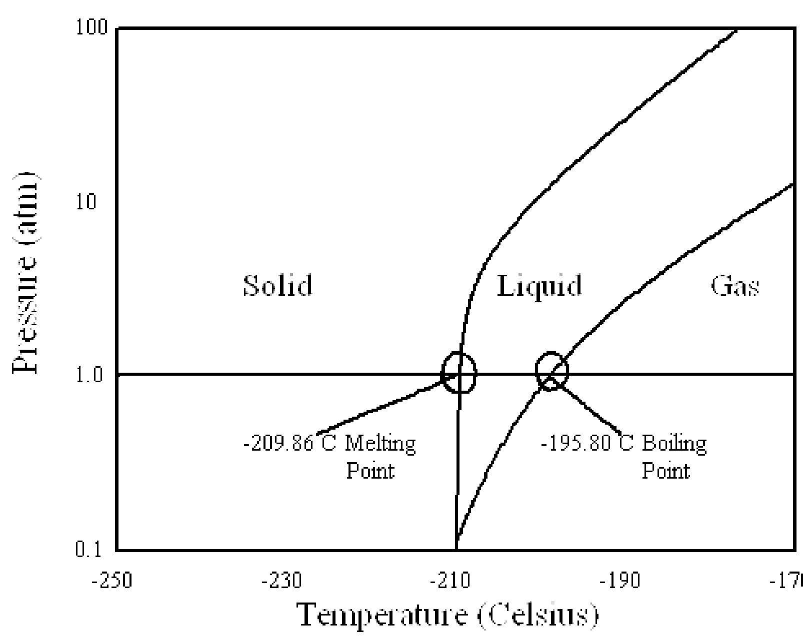


Table) The group of elements nitrogen sits in is referred to as the pnictogens consisting of nitrogen, phosphorus, arsenic,

antimony, and bismuth. (Nitrogen) It follows that nitrogen's electron configuration is $1s^2$ $2s^2$ $2p^3$ and it has three valence electrons. (Periodic Table) Nitrogen has an electronegativity of 3.04 and an atomic radius of 155 pm. (Atomic Radius of the Elements) As a diatomic fluid, nitrogen has a boiling point of -196 ºC and a freezing point of -210 ºC at standard atmospheric pressure of 101.325 KPa. (The Element Nitrogen) (See figure 1 for a phase diagram of nitrogen.) In gaseous form, nitrogen is colorless, odorless, and inert. (The Element Nitrogen) It has a density of 1.25 kg / m^3 at S.T.P. (The Element Nitrogen) Though not common, nitrogen as a solid forms hexagonal crystals. Both in fluid and crystal forms, nitrogen exhibits the properties of an element. (Periodic Table: Nitrogen) This includes aligning with the mole concept.

Mole Concept

The mole concept states that Avogadro's number of particles makes one mole of particles. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Regarding compounds of the periodic table, it asserts that the number of moles of a molecule is equal to its mass divided by the sum of the atomic masses for each type of element. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) In nitrogen this rule can be seen. Since the standard atomic mass of nitrogen is 14.00674 amu and nitrogen is diatomic, one molecule of nitrogen gas has a molecular weight of 2 × 14.00674 or 28.01348 mmu. A gram of pure nitrogen gas would then contain 1 g ÷ 28.01348 mmu or 0.035697 moles.

Although 14.00674 amu is what is referred to as the standard atomic mass of nitrogen, this is not the actual atomic mass of nitrogen. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) On the Earth, there are actually two isotopes of nitrogen found naturally occurring. The most abundant isotope of nitrogen, nitrogen-14, makes up 99.632% of nitrogen on Earth. (Table of Isotopic Masses and Natural Abundances) The actual atomic mass of this isotope is 14.003074 amu. (Table of Isotopic Masses and Natural Abundances) It is used in almost all nitrogen applications. (Table of Isotopic Masses and Natural Abundances) Nitrogen-15 composes 0.368% of nitrogen on Earth. (Table of Isotopic Masses and Natural Abundances) It too is used under all standard nitrogen applications. (Table of Isotopic Masses and Natural Abundances) Nitrogen-15 has an atomic mass of 15.000109. (Table of Isotopic Masses and Natural Abundances) These are the only stable isotopes of nitrogen. (Table of Isotopic Masses and Natural Abundances) Nitrogen-13 does exist. (13-N) However, it has a half-life of only 9.965 minutes. (13-N) It is not found in nature. (Table of Isotopic Masses and Natural Abundances)

Since nitrogen is under standard conditions a gas, no discussion of the mole concept with nitrogen would be complete without mention of the Ideal Gas Law. (IDEAL GASES AND THE IDEAL GAS LAW) This law states that $PV = nRT$ or that the product of the pressure and volume of a gas equals the product of the number of moles of that gas, the gas constant, and its temperature. (IDEAL GASES AND THE IDEAL GAS LAW) While pressure P, volume, V, number of moles n, and temperature T are extensive properties different for each gas and condition, the gas constant R is an intensive constant used for all gasses in the Ideal Gas Law equal to 8.31441 J K^{-1} mol^{-1} or 82.053 cm^3 atm K^{-1} mol^{-1}. (IDEAL GASES AND THE IDEAL

GAS LAW) It is worth noting that this is an *ideal* gas model. Most gases tend to behave in a less than ideal manner as pressure increases. (IDEAL GASES AND THE IDEAL GAS LAW)

Periodic Situation and Trends

As previously discussed, nitrogen is element number 7, lying in the 15th group and second period of the periodic table. (Periodic Table) It displays many of the commonly seen periodic trends on the periodic table including: ionization energy, electronegativity, atomic radius, valance electrons, subshells filled, and metallic character. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) These periodic trends will now be examined individually by discussing what the property is, how it is seen on the periodic table, and how nitrogen conforms to each trend.

Ionization energy is the measure of energy required to remove the highest energy level electron. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Ionization energy peaks at the top and right portion of the periodic table, except for the transition metals where ionization energy peaks at the lower right portion of the d-bock. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Nitrogen well follows this periodic trend because: it has a higher ionization energy for carbon, to its left; has a lower ionization energy than fluorine, to its right; and has a much higher ionization energy than phosphorus, below it. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012)

Electronegativity is “the measure of the ability of an atom that is bonded to another atom to attract electrons to itself.” (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) This is an especially important attribute of elements, because it can be used to predict whether a binary compound is a nonpolar molecule, polar molecule, or ionic compound. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) This trend is seen on the periodic table in a manner very similar to that of ionization energy. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) It peaks at the upper right corner of the periodic table while also peaking in the transition metals on the bottom right center. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Nitrogen well displays this trend. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) It has an electronegativity higher than that of carbon, lower than oxygen, and higher than phosphorous. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012)

Atomic radius is the measure of the size of an atom. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) It peaks at the lower left corner of the periodic table. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Nitrogen follows this trend. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) It has a larger atomic radius than oxygen but less than carbon and less than phosphorus. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012)

Valance electrons are the number of electrons in the valence shell of an atom. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) This number generally increases to the right from one to eight except for the first period which has only the valance electrons of one and two for hydrogen and helium respectively. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Nitrogen follows this trend because it has five valance electrons, more than carbon and less than oxygen. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012)

Subshells filled. The number of subshells filled generally increase to the right and down on the periodic table. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Nitrogen shows this trend because it has more subshells filled than helium and lithium while having less filled than xenon and neon which are below and to the right of it. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012)

Metallic character increases from right to left and top to bottom, peaking at the bottom left corner of the periodic table. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) It is the measure of how metallic an element is. (Periodic Table) A zigzag line separates nonmetals from metals with a transition of metalloids on the periodic table. (Periodic Table) Nitrogen lies to the right of this line, thus it is a nonmetal. (Periodic Table)

How Isolated

Nitrogen can be isolated in a variety of ways. (Cryogenic air separation, 2006) Typically, cryogenic distillation and variations of this method are used to extract, filter, or isolate it from the atmosphere. (Cryogenic air separation, 2006) Also, a variety of chemical reaction can produce nitrogen gas. (Nitrogen - How Nitrogen Is Obtained)

Cryogenic gas distillation is the extraction of major gas components of a gas mixture by cooling the mixture below the melting points of its major components and then selectively allowing the individual components to evaporate for collection. (Cryogenic air separation, 2006) Since nitrogen liquefies at -195.8 ºC and oxygen liquefies at -183.0 ºC at standard pressure, air from the atmosphere can be captured and cooled to temperatures below its critical point.

(Cryogenic air separation, 2006) At 6 bar, air must be cooled to only -172 ºC. (Cryogenic air separation, 2006) This is exactly the process performed at one major air distillation company, Linde. (Cryogenic air separation, 2006) There, one air is pressurized and cooled, it is repeatedly allowed to evaporate at specific temperatures so that oxygen, nitrogen, and argon can be refined with a concentration above 99.9996%. (Cryogenic air separation, 2006) This process is used to produce most commercially used nitrogen. (Cryogenic air separation, 2006)

Multiple chemical reactions can also be used to produce nitrogen as is seen by the following reactions: $2NH_3 + 3Br_2 \rightarrow 6HBr + N_2$; $NH_3 + M_{metal}O \, \Delta \rightarrow M_{metal} + H_2O + N_2$; $Ba(N_3)_2 \, \Delta \rightarrow 3N_2 + Ba$; $2NaN_3 \Delta \rightarrow 3N_2 + 2Na$; and $NH_4NO_2 \xrightarrow[\Delta]{} N_2 + 2H_2O$. (Nitrogen - How Nitrogen Is Obtained) These are just a few chemical reactions that can be used to produce nitrogen. (Nitrogen - How Nitrogen Is Obtained) However, these methods aren't used as often as cryogenic distillation, which is prized for its efficiency. (Cryogenic air separation, 2006) Regardless of how it is purified though, nitrogen must be found in existence as an element for any of these processes to work. (Cryogenic air separation, 2006)

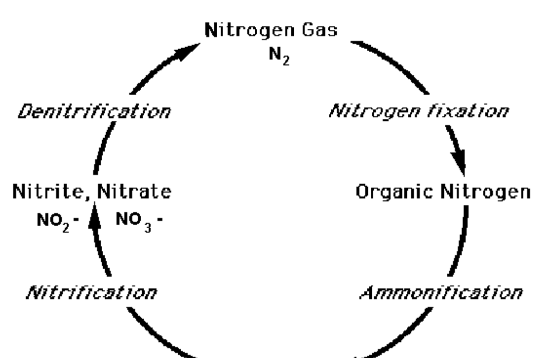
Where Found

Nitrogen is found almost everywhere in the universe. (Nitrogen) As a product of the carbon cycle, nitrogen is found in every star that uses the carbon cycle to make light and even as traces in other stars. (Nitrogen) It is estimated to be the seventh most abundant element in the solar system. (Nitrogen) On earth, nitrogen composes 78% of the atmosphere (Nitrogen) and 0.002% of the crust. (Abundance in Earth's Crust of the elements) Nitrogen is found in 0.5 ppm in the ocean. (Element Abundances in Ocean Water) The human body is 3.2% nitrogen by weight. (Building Blocks of Life) Nitrogen therefore, is a very common element.

Many naturally occurring nitrogen compounds are found in chemical compounds on Earth. Nitrates are commonly found as minerals in the crust. (Saltpeter) Among these are saltpeter, or potassium nitrate, and sodium nitrate. (Kurtus, 2007) Ammonia and ammonium hydroxide also are frequently seen. (Jewell, Kimbal, 2016) These compounds form the base for many more compounds in organic chemistry. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012)

Urea and nucleobases are commonly seen organic nitrogen containing compounds. (Urea) Urea, also known as carbamide, is an organic compound with the chemical formula $CO(NH_2)_2$. (Urea) It is used in the human body most noticeably in excretion of nitrogen. (Urea) Nucleobases are the bases used in forming nucleic acids such as DNA and RNA. (Nucleobases and Their Production during the Photolysis of Astrophysically-relevant Ices, 2016) Nitrogen plays an important role in forming bases such as: Adenine, Guanine, Uracil, Thymine, and Cytosine. (Nucleobases and Their Production during the Photolysis of Astrophysically-relevant Ices, 2016) These bases form base pairs which define the makeup and operation of organisms. (Nucleobases and Their Production during the Photolysis of Astrophysically-relevant Ices, 2016) Thus urea and nucleobases are commonly seen nitrogen based compounds.

The Nitrogen Cycle is a process in which nitrogen is exchanged with the inorganic and



organic parts of an ecosystem. (Uman, Rakov, 2007) Since nitrogen in the air forms a nearly inseparable triple bond with itself as nitrogen gas, not many chemical processes can benefit from and harness nitrogen in the air. (Uman, Rakov, 2007) Lightning bolts however can ionize the air around itself, causing nitrogen to break apart into ions. (Uman, Rakov, 2007) This process is known as fixation. (Uman, Rakov, 2007) Some of these are free nitrate ions. (Uman, Rakov, 2007) These and other nitrogen-based ions can then be used by organisms to create organic compounds. (Uman, Rakov, 2007) These organic compounds are then converted into ammonium in a process known as ammonification. (Uman, Rakov, 2007) Nitrification then converts the ammonium ions into nitrate and nitrite ions. (Uman, Rakov, 2007) Finally, thru denitrification, nitrogen from nitrate and nitrite ions is converted back into diatomic nitrogen gas. (Uman, Rakov, 2007) (See figure 2 for a graphical representation of this process.)

Uses

Humans have taken on the use of nitrogen for a variety of purposes. Nitrogen serves as an essential nutrient in the human body. (Use of Nitrogen) In fact, "A healthy adult male needs about 105 milligrams of nitrogen per kilogram [of body weight], or per 2.2 pounds per day" (Why Does the Body Need Nitrogen) It is used in hemoglobin to aid the transportation of oxygen around the body. As previously mentioned, nitrogen composes DNA, RNA, and urea. (Nucleobases and Their Production during the Photolysis of Astrophysically-relevant Ices, 2016) All proteins and amino acids eventually breakdown into ammonia, a nitrogen containing compound. (Use of Nitrogen) Nitrogen is also used as an anesthetic in the pharmaceutical industry in the compound nitrous oxide. (Uses of Nitrogen)

In addition to the numerous biological uses of nitrogen, it fulfills many industrial applications. Diatomic, gaseous, nitrogen has a large atomic radius of 155pm. (Nitrogen) That means is does not leak in between microscopic holes or spaces in materials like thermoplastics, thermosetting polymers and elastomers, or between the junctions of two tightly sealed connections. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Another advantage to nitrogen gas is its stability. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) Nitrogen is not flammable. (Brown, LeMay, Bursten, Murphy, & Woodward, 2012) That is why nitrogen is a preferred gas for pressurizing automobile tires. (Uses of Nitrogen) It also is used in demanding aircraft pneumatic applications. (Uses of Nitrogen) Many paintball guns used to be powered by compressed carbon dioxide but now nitrogen has largely replaced its use. (Uses of Nitrogen) Since nitrogen has a freezing point of -210 ^{o}C, it offers an inexpensive solution for low temperature cooling applications. (Uses of Nitrogen) Nowadays, nitrogen is used as a coolant in everyday environments such as computers and X-ray machines. (Uses of Nitrogen)

Nitrogen has many uses. It is an essential nutrient to humans and fulfills numerous industrial and commercial applications. It is not surprising, then, that nitrogen has taken on so many uses.

Conclusion

Nitrogen is an amazing element. It lies on the second period in the 15th row of the periodic table. Formed within the cores of powerful carbon cycle thermonuclear fusion stars, it is the seventh most abundant element in the universe. For millions of years, nitrogen has served as an essential element in the core of life sustaining organic compounds. From ancient times, the universe was thought to have been made out of four fundamental components: earth, water, fire, and air. However, in the late 18th century, a wave of interest swept across understanding gasses. In 1774, Daniel Rutherford discovered what he called “noxious air.” This was the long sought after mysterious element. Nitrogen today is refined in a variety of way but primarily through cryogenic distillation. It is used is many modern applications such as providing pressurized air for tires and pneumatic landing gear and serving as an inexpensive liquid coolant.

References

Brown, T. L., LeMay, H. E., Bursten, B. E., Murphy, C. J., & Woodward, P. M. (2012). *Chemistry The Central Science.* Prentice Hall.

Nitrogen. (n.d.). Retrieved November 14, 2016, from http://ecosystems.mbl.edu/Research/Clue/nitrogen.html

Urea. (n.d.). Retrieved November 14, 2016, from https://en.wikipedia.org/wiki/Urea

Ideal gases and the ideal gas law: PV = nRT. (n.d.). Retrieved November 14, 2016, from http://chemguide.co.uk/physical/kt/idealgases.html

It's Chemically Delicious! (n.d.). Retrieved November 14, 2016, from https://itschemicallydelicious.wordpress.com/tag/nitrogen/

Joseph Priestley, Discoverer of Oxygen National Historic Chemical Landmark - American Chemical Society. (n.d.). Retrieved November 14, 2016, from https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/josephpriestleyoxygen.html

Periodic Table – Royal Society of Chemistry. (n.d.). Retrieved November 14, 2016, from http://www.rsc.org/periodic-table/

Periodic Trends. (2016). Retrieved November 14, 2016, from http://chem.libretexts.org/Core/Inorganic_Chemistry/Descriptive_Chemistry/Periodic_Trends_of_Elemental_Properties/Periodic_Trends

Chemical Elements.com - Nitrogen (N). (n.d.). Retrieved November 14, 2016, from http://www.chemicalelements.com/elements/n.html

Why Does the Body Need Nitrogen? (2015). Retrieved November 14, 2016, from http://www.livestrong.com/article/500133-why-does-our-body-need-nitrogen/

Uses of Nitrogen | Uses Of. (n.d.). Retrieved November 14, 2016, from http://www.usesof.net/uses-of-nitrogen.html

Atomic Radius of the elements. (n.d.). Retrieved November 14, 2016, from http://periodictable.com/Properties/A/AtomicRadius.v.log.html

Winter, M. (n.d.). Nitrogen: Electronegativity. Retrieved November 14, 2016, from https://www.webelements.com/nitrogen/electronegativity.html

Nitrogen. (n.d.). Retrieved November 14, 2016, from https://en.wikipedia.org/wiki/Nitrogen

Chemical Elements.com - Nitrogen (N). (n.d.). Retrieved November 14, 2016, from http://www.chemicalelements.com/elements/n.html

The Element Nitrogen. (n.d.). Retrieved November 14, 2016, from http://education.jlab.org/itselemental/ele007.html

Nitrogen Element Facts. (n.d.). Retrieved November 14, 2016, from http://www.chemicool.com/elements/nitrogen.html

Eni Generalic, Faculty of Chemistry and Technology, Split, Croatia. (n.d.). NITROGEN. Retrieved November 14, 2016, from http://www.periodni.com/n.html

Saltpeter | KNO3 - PubChem. (n.d.). Retrieved November 14, 2016, from https://pubchem.ncbi.nlm.nih.gov/compound/potassium_nitrate

Mineral Commodity Summaries 2016. (n.d.). Retrieved November 14, 2016, from http://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf

Nucleobases and Their Production during the Photolysis of Astrophysically-relevant Ices. (n.d.). Retrieved November 14, 2016, from http://www.astrochem.org/sci/Nucleobases.php

PowerPoint Presentation. (n.d.). Retrieved November 14, 2016, from http://www.che.ufl.edu/unit-ops-lab/Poster/Poster-2015-Spring-Cryogenic-separations.pptx

(n.d.). Retrieved November 14, 2016, from http://www.answers.com/Q/How_is_nitrogen_obtained

Winter, M. (n.d.). Nitrogen: The essentials. Retrieved November 14, 2016, from https://www.webelements.com/nitrogen/

School of Life Sciences | Ask A Biologist. (n.d.). Retrieved November 14, 2016, from https://askabiologist.asu.edu/content/atoms-life

Element Abundances in Ocean Water | The Elements Handbook at KnowledgeDoor. (n.d.). Retrieved November 14, 2016, from http://www.knowledgedoor.com/2/elements_handbook/element_abundances_in_ocean_water.html

Abundance in Earth's Crust of the elements. (n.d.). Retrieved November 14, 2016, from http://periodictable.com/Properties/A/CrustAbundance.an.html