INTRODUCTION TO CHEMISTRY - Chapter 1

"Wherever we look, the work of the chemist has raised the level of our civilization and has increased the productive capacity of our nation." Calvin Coolidge, 30th President of the U.S.

http://commons.wikimedia.org/wiki/File:Calvin_Coolidge,_Mrs._Coolidge_and_Senator_Curtis.jpg

Calvin Coolidge

"Chicken fizz! O Lord, protect all of us who toil in the vineyards of experimental chemistry!" Alan Bradley, author of the a best selling mystery series of books puts these words in the mouth of an 11 year old girl, Flavia de Luce, who has a substantial ability to apply chemistry to her detective work. This quotation came from the most famous of the series, *The Sweetness at the Bottom of the Pie*.

"Here's what I've learned about deal-breakers. If you have enough natural chemistry with someone, you overlook every single thing that you said would break the deal." Taylor Swift, pop singer.

What is chemistry and what do we need to know about it? The three quotations above present highly diverse uses of the word, chemistry. Many linguists attribute the word chemistry to an ancient Egyptian name meaning "black earth". Others say chemistry is derived from a Greek word that means pouring and still others say the origin is from a Persian word that translates as "gold" http://en.wikipedia.org/wiki/Chemistry_(word) or a Chinese word that means "secret of gold" http://hilltop.bradley.edu/~rbg/Origin.html. For a good discussion of the origin of chemistry that you should enjoy reading, please visit:
http://www.sciencefriday.com/segment/08/26/2011/science-diction-the-origin-of-chemistry.html

A search for the definition of chemistry in dictionaries and encyclopedias will lead to many variations but one of the best is quoted below from Britannica:
Chemistry, the science that deals with the properties, composition, and structure of substances (defined as elements and compounds), the transformations they undergo, and the energy that is released or absorbed during these processes.
http://www.britannica.com/EBchecked/topic/108987/chemistry
Another perspective is that science is a search for relationships and order in the Universe and chemistry would be a search for order in matter. This is much more profound than it sounds. Consider a phone book as an example. It is ordered alphabetically. If the names were arranged randomly, it could take ages to find a person of interest. By alphabetizing the names, the task is simplified and substantial valuable time is saved. By finding the relationship between phenomena and actions, it is much easier to understand and explain phenomena and actions and very importantly predict outcomes in future observations. Since the primary goal of chemistry is to provide an understanding of matter, the development of models that account for the similarities and differences between different types of matter is a major goal of chemistry. The periodic table is a wonderful example of the results of the quest for a search for order in matter.

The three quotations about chemistry deserve some more attention. Almost 100 years ago, Calvin Coolidge recognized that chemistry makes significant contributions to our quality of life. From the structural material provided by plastics to medicines, pesticides and combustion, we use the products of chemistry all the time. However, there also sometimes have been accompanying negative consequences that need to be confronted and mitigated. In some cases, these consequences have very long term deleterious effects that require a society literate in chemistry if we want to maintain and increase our quality of life.

The second quotation demonstrates the common frustration experienced by the laboratory chemist. Chemistry is a very complicated field that is dependent on many variables such as temperature, pressure, amounts, purity and even the procedure (mixing A into B might give different observations than mixing B into A). One of the characteristics of science including chemistry is that an experiment must be reproducible. It is often difficult when performing a chemical reaction or test to make sure that all of the variables are exactly the same as for a previous run. In addition, chemical reactions can give off terrible smelling, sometimes toxic gases and on rare occasions give off enough energy and gas to result in an explosion. Slight differences can cause significantly different outcomes and Flavia de Luce is probably expressing her frustration because of unexpected and disgusting results from one of her experiments.

The third quotation uses chemistry essentially as a synonym for love. This use is not a topic for this book but illustrates the ubiquity of chemistry in our lives. We must strive to understand chemistry not just as individuals but as a society. Decisions on issues such as ozone depletion, climate change and environmental pollution will take international cooperation and action. Taking the best pathways to overcome the challenges requires a society literate in chemistry. From the perspective of individuals, a background in chemistry can help you choose household and personal products, over the counter medicines and the type of automobile engine.

It is worthwhile to pay attention to the words of some of the wisest of people before we start our adventure into the fascinating, exciting and complex field of chemistry. First, Socrates recognized that *"True wisdom comes to each of us when we realize how little we understand about life, ourselves, and the world around us."* Newton recognized that a person should scour the literature on a topic before stumbling forward when he said, *"If I have seen further it is by standing on the shoulders of Giants."* Einstein encouraged us to use our minds to dream and ponder the unknown when he said, *"Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand."* Continuing on this theme, one of the most famous chemists of the 20th century and the only person to have ever won two unshared Nobel prizes surprisingly in different fields (chemistry and peace), Linus Pauling, said *"If you want to have good ideas you must have many ideas. Most of them will be wrong, and what you have to learn is which ones to throw away."*

To summarize, when investigating a topic of interest and importance, we first need to be sure that we are familiar with the reports of previous studies on the topic. We must start with an open mind and be prepared to accept counter intuitive explanations. We need to think deeply about the subject and not be afraid of making mistakes but very importantly **be willing to learn from our mistakes.** For this semester, the excitement that usually accompanies the first day of class often clashes with anxiety that results from a lack of confidence that your new courses will be interesting and survivable. But survivable should not be sufficient for you. Science and especially chemistry courses have reputations that intimidate many students. But, your explorations into the field of chemistry will provide you with new insights that will make your life more enjoyable and rewarding and give you confidence that you are better prepared to make more informed decisions on many of the choices that will confront you as you try to maximize your contributions to the health and welfare of society. **Please remember that the amount of learning you gain from this course as with most endeavors depends on how much effort you invest in learning the material.**

One of the greatest physicists of the 20th century, Richard P. Feynman, titled a book *The Pleasure of Finding Things Out*, that describes an attitude that we should all strive for as we explore the chemistry that should prove useful to us. Please visit at least one of the sites below and listen to Dr. Feynman. These videos should give you some insight into the view of the world of this great scientist and the way that his mind worked.

http://www.ted.com/talks/richard_feynman
http://www.youtube.com/watch?v=Bgaw9qe7DEE
http://www.youtube.com/watch?v=FXiOg5-I3fk (Not synchronized)
http://www.feynman.com/
http://www.richard-feynman.net/videos.htm

To facilitate your exploration of chemistry related issues that impact your life and to enhance your ability to apply your understanding to the solving of problems, some basic chemistry and terminology needs to be learned. Later in the course, additional chemistry will be presented as needed for the understanding of topics and concerns. Chemistry is the study of matter, its physical and chemical properties and the energy changes that are associated with physical and chemical changes. Matter is all the stuff around us that we can see, smell, touch or sense (the air in a balloon is not visible to us nor can we detect it by touch but we can sense its presence when the wind blows). Matter is composed of substances and there are two kinds of substances, elements and compounds. Elements are substances that cannot be broken down into simpler substances by chemical means. Compounds are substances composed of two or more elements combined in a definite ratio. To a non-chemist, the word substance probably means something like stuff but to a chemist, substance has a much more specific meaning. The word pure is implied by the word substance as a substance is a single type of chemical, be it an element or a compound. A substance cannot be separated into simpler substances by use of a physical process such as filtering or distillation.

Most of the stuff we encounter in nature is composed of two or more substances and is referred to as a mixture. Mixtures can be separated into substances using a physical process. A mixture of sand and water can be separated by filtration and salt water can be separated into salt and water by distillation to remove the water leaving the salt in the boiling flask.

A compound differs from a mixture in several ways. First the compound consists of two or more elements combined chemically in a definite ratio. Water or H_2O is derived from the combination of 2 atoms of hydrogen and 1 atom of oxygen. Hydrogen peroxide (H_2O_2) is derived from 2 atoms of hydrogen and 2 atoms of oxygen and has properties that are considerably different than water despite the similar composition. Neither water or hydrogen peroxide resembles the hydrogen and oxygen that compose it. In other words, the properties of compounds cannot be predicted from the properties of their component atoms. Unlike mixtures, compounds cannot be separated into elements using a physical process but can be broken down into elements via chemical reactions. As contrasted with compounds, mixtures can contain different ratios of substances and therefore the percentage of each element present is not fixed as it is with a compound. As an example of the variable composition of mixtures, salt water can contain any amount of NaCl between 0% and 26% salt before the water is saturated with NaCl.

As stated, most of the stuff we encounter is composed of mixtures. Chemists commonly need to analyze the mixtures. Despite what you might see during a forensic analysis on TV where simple injections seem to provide unlimited detail, it is usually very difficult to analyze mixtures without first using physical processes to separate the mixture into substances. On the other hand, once substances have been obtained, the chemist has many techniques available that often lead to identification of the substance. Every substance has a unique set of physical and chemical properties. Some of the properties are relatively simple to measure and often enable positive identification of substances. Melting and boiling points, density and refractive index are some of the physical properties used to identify compounds that are analogous to the use of fingerprints for identifying people.

	M. P. (°C)	B. P. (°C)	Density (g/cm^3 @ 20°C)	Refractive Index
water (H_2O)	0.00	100.00	0.998	1.3330
hydrogen peroxide (H_2O_2)	-0.43	150.2	1.45	1.4061
acetyl salicylic acid (Aspirin)	136		1.40	
acetaminophen (Tylenol)	169		1.26	

For example, water and hydrogen peroxide can be distinguished using a boiling point or density measurement. The active ingredients of aspirin and Tylenol can be apparently be distinguished in minutes with a melting point measurement. However, as aspirin and Tylenol tablets contain binders in addition to the active components, a separation that could be time consuming must be performed before the melting point is determined. Chemical reactions can also be used to characterize a compound. Water will sit is a closed container at room temperature indefinitely but pressure will build up in a closed bottle of hydrogen peroxide (potentially dangerous) due to its decomposition to oxygen and water.

Just to give you a sense of the possible range of density measurements, please examine the table below.

Object	density (g/cm^3)	Notes
universe	1×10^{-30}	Average value as most of the Universe is empty space
air	1.48×10^{-3}	sea level, 20°C
water	0.998	20°C
sun	1.4	Average value that varies significantly from core to edge
aluminum	2.7	
Earth	5.51	
lead	11	
white dwarf	1×10^{6}	
proton	4×10^{12}	
neutron star	5×10^{14}	
black hole	6×10^{15}	This is an estimate but some place the value as infinite

water and aluminum represent the three common states of matter we are all familiar with: gases, liquids and solids. In solids, the atoms, ions or molecules are very close together with crystalline and/or attractive forces keeping them in fixed positions relative to one another. If sufficient energy is added to overcome the attractions that maintain the structure of the solid, the substance melts and the atoms or molecules while still attracted to each other will slide by each other forming a liquid. If additional energy is added that overcomes the attractive forces, boiling occurs and the substance undergoes a phase change into a gas. The table below compares some of the primary properties of solids, liquids and gases.

Liquid and solid water

Liquid and solid aluminum

solids	liquids	gases
fixed volume and shape	assume shape of occupied part of container	assume shape of entire container
particles adjacent to each other in fixed positions	particles adjacent to each other but slide by each other	particles far apart but do bump into each other elastically
not easily compressible	not easily compressible	compressible

It is important to note that the paragraph above included the word "common" before *three states of matter*. While true that the physical world we focus on includes three states of matter, other states of matter are actually more common in the Universe. The state of matter of stars is called a plasma. In recent years, cosmologists have become convinced that much of the Universe is composed of dark matter.

There is actually another state of matter that is becoming more common called a liquid crystalline state. It has properties that seem to be between those of a liquid and solid although liquid crystals have some unique properties that make them very useful in today's high technological world.

Liquid crystal display (LCD)

Most substances found in nature are compounds. Only a few elements occur in their elemental state. However, some of the naturally occurring elements such as oxygen are extremely important. In addition, an understanding of some of the properties of elements will help us understand why the elements react to form compounds. Many attempts had been made to organize the elements into a useful scheme but it was not until 1869 that a meaningful table was published by Dimitri Mendeleev.

http://web.lemoyne.edu/~giunta/EA/MENDELEEVann.HTML
http://web.lemoyne.edu/giunta/mendel.html
http://en.wikipedia.org/wiki/History_of_the_periodic_table
http://www.aip.org/history/curie/periodic.htm

Before discussing Mendeleev's groundbreaking publication, it is informative to review the history of chemistry up to the time of his publication. During the time of the great Greek city-states or a few hundred years B.C., Greek philosophers pondered the nature of matter. It is important to understand that Greek philosophers did not fit the criteria currently used to describe scientists. They did not perform experiments to test their ideas. A lesser known philosopher named Democritus and some of his colleagues proposed that matter, if divided time after time, would eventually result in an particle that could not be divided further. They used the term *atomos* meaning indivisible to describe this particle. Many decades later, the more famous philosophers, Plato and especially Aristotle did not support the atomos concept and claimed that matter is continuous and could be divided endlessly. Because Aristotle was much more influential than Democritus, the continuous matter concept dominated for the next 2000 years. In addition, only four elements were considered relevant and necessary for the formation of all matter; earth, air, fire and water. During this time, the field of alchemy emerged but the approach used by the alchemists did not fit into the realm of science. Among the primary goals of the alchemists was an attempt to find a technique for converting lead into gold. Today, we know that this is an impossible task using chemical reactions and only through very expensive nuclear means could this goal be accomplished.
For more information on Democritus and Aristotle, please visit:

http://www.infoplease.com/ipa/A0905226.html
http://www.chemistryexplained.com/Ar-Bo/Atoms.html
http://www.angelfire.com/alt2/atom/sci2.html
http://www.scienceclarified.com/everyday/Real-Life-Chemistry-Vol-1/Atoms-Real-life-applications.html

Paintings of alchemists. Some of the many notable paintings of alchemists provide you a glimp se of the labs of alchemists and the attitude of society toward alchemy. Please notice in the first painting of an alchemist by Peter Brueghel that alchemistry was not necessarily a good way to make a living as the family of the alchemist is headed into the poor house. Another example is available at: http://murov.info/alchemists.htm.

http:/
/upload.wikimedia.org/wikipedia/commons/thumb/4/4b/Pieter_Brueghel_-_Der_Alchimist.jpg/640px-Pieter_Brueghel_-_Der_Alchimist.jpg

http://upload.wikimedia.org/wikipedia/commons/thumb/0/00/Alchemist_Penn.JPG/360px-Alchemist_Penn.JPG
http://upload.wikimedia.org/wikipedia/commons/9/9f/Hennig_Brand_%28Joseph_Wright%29.jpeg

Robert Boyle

It was not until the 17th century that the field of chemistry began to emerge and researchers began to rethink the concepts of matter. People like Robert Boyle (born in Ireland to English parents) started to do legitimate chemistry by performing quantitative and reproducible experiments. Boyle's experiments and thoughts resulted in one of the laws that relates the volume of a gas to pressure and to the publication of what is regarded as the first chemistry book, *The Sceptical Chymist*.
http://www.gutenberg.org/files/22914/22914-h/22914-h.htm
You should visit this site and read a few of the pages while remembering that this book was published in 1661.

Antoine Lavoisier

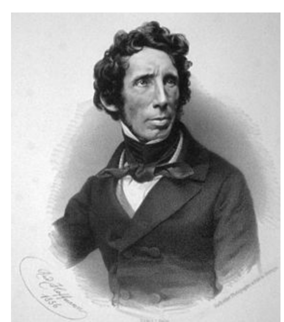
Late in the 18th century, a French nobleman, Antoine Lavoisier, performed experiments that disproved the four element concept and the prevailing phlogiston concept (a fire-like element called *phlogiston*, contained within combustible bodies, is released during combustion). He demonstrated that mass (within measurable limits) is conserved in chemical reactions. Unfortunately, in the midst of his very productive career as an experimental chemist, Lavoisier, as a result of his status and other occupation (tax collector), was guillotined during the French revolution.

John Dalton

Other chemists demonstrated that compounds were composed of elements combined in a definite ratio. This observation could not be explained by the continuous matter concept. How could water be two parts hydrogen and one part oxygen if particles of hydrogen and oxygen did not exist? Based on his own experimental results and those of Boyle, Lavoisier and others, an Englishman, John Dalton concluded that the atomos concept of Democritus had been correct. In 1803, Dalton published an atomic theory and most parts of the theory stand as correct today.

1. Elements are made of extremely small particles called atoms
2. Atoms of a given element are identical in size, mass, and other properties atoms of different elements differ in size, mass, and other properties.
3. Atoms cannot be subdivided, created, or destroyed.
4. Atoms of different elements combine in simple whole-number ratios to form chemical compounds.
5. In chemical reactions, atoms are combined, separated, or rearranged.

http://en.wikipedia.org/wiki/John_Dalton



Fredich Wöhler

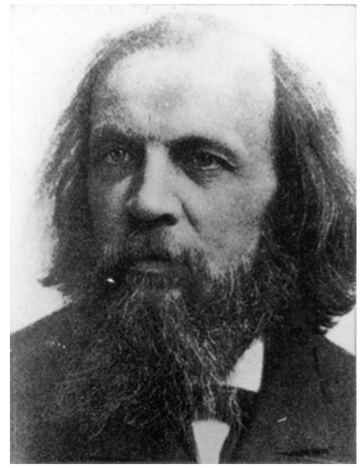
Chemists at the time in addition to the phlogiston concept also thought that chemicals derived from anything living contained a mysterious quality called *vitalism*. However, in 1828, Fredrich Wöhler was able to demonstrate that the urea obtained from non-living sources is identical to the urea obtained from living sources. It took many decades for the phlogiston and vitalism concepts to totally lose acceptance and enable the advancement of chemistry. Until that time, the field of organic chemistry was considered to be the chemistry of substances derived from living sources but post-Wöhler became the chemistry of compounds that contain carbon. It is interesting to read Wöhler's thoughts on this important branch of chemistry.

Organic chemistry nowadays almost drives me mad. It gives me the impression of a primeval tropical forest, full of the most remarkable things, a monstrous and boundless thicket, a dreadful, endless jungle with no way of escape, into which one may well dread to enter for there seems no way out.

The Periodic Table. With the debunking of the four element concept, the phlogiston postulate and vitalism and very importantly, the discovery of many elements, the stage was now set for the Russian, Dimitri Mendeleev to develop the periodic table. Several chemists including the German, Lothar Meyer, had produced periodic tables but Mendeleev was the first to use his table to predict properties of previously unknown elements. By 1869 when Mendeleev published his first version of the periodic table, about 60 elements had been characterized. One of the properties of the elements that had been determined was the relative mass of an atom of the element. Mendeleev arranged the elements by increasing atomic mass. In addition, Mendeleev noticed that elements could be grouped according to similarities in chemical reactivities and formulas of compounds. These similarities among groups existed despite big gaps in the atomic masses of members of the group. For example, group 1A alkali metals lithium, sodium, potassium, rubidium and cesium all react violently with water to give hydrogen and a basic solution. In addition the products of the reaction with water for this group are LiOH, NaOH, KOH, RbOH and CsOH, all with a 1 to 1 ratio of the metal with OH. The elements adjacent to the above elements (the element next according to increasing atomic mass), berylium, magnesium, calcium, strontium and barium form bases with the formula $M(OH)_2$ and chlorides with the formula MCl_2. In a similar manner, the elements fluorine, chlorine, bromine and iodine form compounds with sodium that all have the formula NaX (X represents any member of the group called halogens). When Mendeleev started new periods with each alkali metal, he found that the resulting elements from the alkali metals across to the halogens lined up vertically in a group or family with similarities of chemical properties and formula ratios. It turns out that this is an oversimplified picture but basically this type of thinking led Mendeleev to the organization of the elements that forms the basis for contemporary periodic tables. Conspicuously absent from the Mendeleev table were the inert gases (elements that unless forced under extreme conditions do not combine with other elements and exist in nature in elemental form). Helium had been observed in the sun at about the time Mendeleev produced his first table but it was not until 1895 that Sir William Raleigh and others were given credit for actually discovering helium.

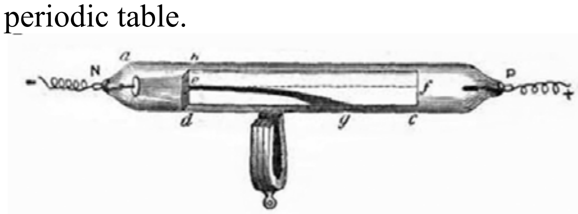
In some cases, there were elements such as galium that had not yet been discovered. However, Mendeleev realized that germanium belonged below carbon and silicon and not below boron and aluminum. Therefore, he left an empty space for gallium but did predict its properties based on the elements above, below, left and right of the space. Given its predicted properties, scientists were able to discover gallium and found that Mendeleev's predictions were quite good. In addition, Mendeleev noticed that based on properties, iodine belonged in the same group as the other halogens but its atomic mass would have placed it before tellurium or in a dissimilar group. Because atomic mass measurements at that time were subject to substantial error, Mendeleev assumed the atomic masses of iodine and/or tellurium has been measured incorrectly and he placed both elements in their correct groups. It turns out that the atomic masses were actually precise and exhibit an inversion from expectations. Thus Mendeleev placed them correctly but for an incorrect reason. As stated earlier, when an observation is made that is not consistent with expectations, questions need to be raised and the situation studied further. While the concept of atoms had been accepted by the time of Mendeleev, a model for the atom and the possible relationship of the atoms

			Ti = 50	Zr = 90	? = 180
			V = 51	Nb = 94	Ta = 182
			Cr = 52	Mo = 96	W = 186
			Mn = 55	Rh = 104,4	Pt = 197,4
			Fe = 56	Ru = 104,4	Ir = 198
			Ni = Co = 59	Pd = 106,6	Os = 199
H = 1			Cu = 63,4	Ag = 108	Hg = 200
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	J = 127	
Li = ?	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		



Dimitri Mendeleev

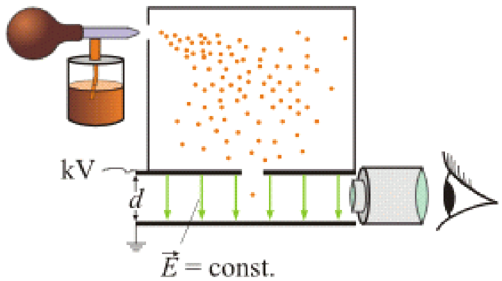
of different elements was still decades off in the future. Later in this brief history it will become easier to understand why iodine and tellurium are in an order inconsistent with their atomic masses. Suffice it to say at this point that atomic mass correlates well but not perfectly with a more basic atomic property, the atomic number. Mendeleev used the best variable available to him, atomic mass, but it turns out that it works for most elements but not all. Mendeleev developed the periodic table based on observations gained from chemistry but still remaining was the reason for similarities and differences among the elements. It was clear from reactivity patterns that the atoms of elements within groups such as lithium, sodium, potassium, rubidium and cesium must have some properties at the atomic level in common. Also, what is changing going from one element to the next heaviest to cause the mass increase. To explore these issues, we need to proceed chronologically as experiments over the next several decades produced a model for the atom that accounts for the shape of the periodic table.



Crookes tube

J. J. Thomson

The Atom. Because of the trends and patterns of the elemental properties, it certainly did seem that atoms of each element must be in some way related to each other. However, there was no concept yet of the architecture of the atom. Could it be a single particle that fills all the space of the atom or could it be made up of smaller particles that are common to all atoms. Because of the patterns, the latter seemed much more likely. Using a Crookes tube like the one in the illustration above, J. J. Thomson was able to show that all atoms contain particles called electrons that have a negative charge and very small mass. From the experiments, Thomson was able to calculate the charge to mass ratio of the electron (e/m).



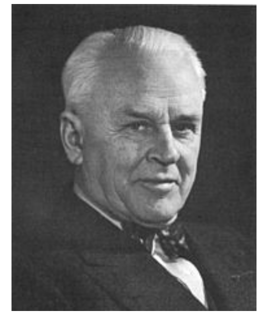
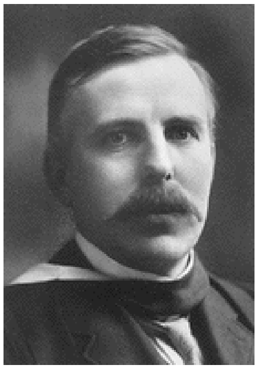


Diagram and pictures of Millikan and his oil drop experiment apparatus

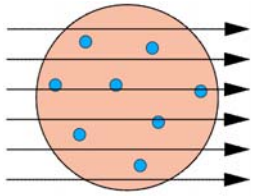
Having the charge to mass ratio of the electron and proton, it was still an interesting and informative challenge to determine the mass of these basic particles. Robert A. Millikan was able to achieve this goal using a cleverly designed oil drop experiment. By producing water droplets with embedded electrons, Millikan was able to determine the voltage needed to prevent gravity caused falling of the droplets. From the voltage needed, he was able to calculate the charge of the electron. Using the e/m ration previously determined by Thompson, Millikan was able to calculate that the electron has the extremely tiny mass of about 9.1×10^{-28} grams. Consequently, the mass of a proton is about 1.67×10^{-24} g.

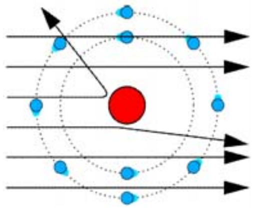
The combined work of many physicists including Ernst Rutherford was able to demonstrate that for every electron, each atom contains a particle with the opposite charge of the electron but 1835 times more massive. This particle was named the proton.

object	mass (g)
electron	9.1×10^{-28}
proton	1.673×10^{-24}
H atom	1.674×10^{-24}
neutron	1.675×10^{-24}
Fe atom	9.27×10^{-23}
U atom	3.95×10^{-22}
paper clip	~1
penny 2.5	
person	$\sim 7 \times 10^{4}$
car	$\sim 1 \times 10^{6}$
moon	7.3×10^{25}
earth	5.97×10^{27}
sun	2.0×10^{33}



Ernst Rutherford





The number of protons in an atom is a fixed characteristic of an element and has been defined as the atomic number. Thus all the atoms of all elements are made up of the same particles, protons and electrons. The number of protons and electrons determines the chemical properties of the element. While unknown to Mendeleev and his contemporaries, the elements should have been arranged according to atomic number and not according to atomic mass. Since atoms are neutral in charge, for every proton, there is an electron. Since the proton is 1835 times as massive as an electron, it was thought that most of the atom was composed of protons with the electrons embedded in them. The words "plum pudding" have been used to describe this model. This concept was debunked when Rutherford performed his very clever gold foil experiment. Using alpha particles from a radioactive source as "bullets", he aimed the particles at a piece of gold foil. Since these particles are highly energetic, based on a plum pudding model, Rutherford expected the particles to go through the foil unimpeded. It would be sort of like firing a gun through a Nerf ball. While most of the particles did go straight through, Rutherford was surprised to notice that occasionally the path of the particles was changed or deflected as they went through the foil and in a few cases particles actually rebounded towards the source. As a result, Rutherford said,

It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.

The experimental results clearly demonstrated that the protons are in the center of the atom but occupy only a very small portion of the volume of the atom. The very concentrated mass in the very small center of the atom is usually not encountered by the alpha particles and the particles go straight through. The electrons having such a low mass do not affect the path of the alpha particles. However, once in a while the alpha particles come close enough to the nucleus to be deflected (alpha particles and protons have the same charge and repel each other). On rare occasions, the alpha particle runs directly in to the protons and is deflected back. Based on these concepts, Bohr developed the solar system model for the atom with the protons in a small volume in the center of the atom and the electrons in orbits around the protons. This model did enable Bohr to accurately calculate the properties of a hydrogen atom but the model failed as soon as two or more protons and electrons were present.

The currently accepted model for the atom is rather abstract. Just like the Big Bang was beyond the capabilities of our imaginations, the atom is difficult to imagine also. Due to the size scale of the atom, our worldly experience does not give us a context for picturing the atom. The best we can do is talk about probabilities. The electron should not be thought of as a particle in an orbit around the protons but a region of space that has the properties of the electron. The shapes, size and orientations in space of these orbitals can be calculated using very sophisticated mathematics. For the hydrogen atom with one proton and one electron, the region of space is indeed spherical in shape. However the shapes increase in complexity as the number of electrons increases and treatment of the shapes of the orbitals (as contrasted with the Bohr orbits) is left for a higher level course.

To complete our working model of the atom, we need to return to the beginning of the periodic table. The simplest element is hydrogen and consists of one proton and one electron. Since the proton weighs 1835 times as much as the electron, almost all of the mass of the atom is due to the proton. If the relative mass of the proton is arbitrarily assigned a value of close to 1, the electron weighs about 0.0005. As expected, hydrogen with atomic number 1 has an atomic mass very close to 1. The next element, helium, should have 2 protons and 2 electrons and a mass of about 2. However, while the 2nd element does have 2 protons and 2 electrons, its mass is found to be about 4 rather than 2. It wasn't until 1932 that Chadwick demonstrated that most atoms contain a third particle with a mass similar to that of a proton but very importantly, no charge. This particle was named the neutron. To explain the observed atomic mass of 4 for helium required that the helium atom contain in addition to the two protons and electrons, two neutrons. Lithium with an atomic mass of about 7 would have 3 protons and electrons and 4 neutrons. Because protons and neutrons have relative mass values very close to unity, the atomic mass is the sum of the number of protons and neutrons in an atom. Subtraction of the atomic number from the atomic mass gives the average number of neutrons in the atom. The inclusion of the word average is important here and will be explained below. The table below gives the number of protons, electrons and neutrons for several elements.

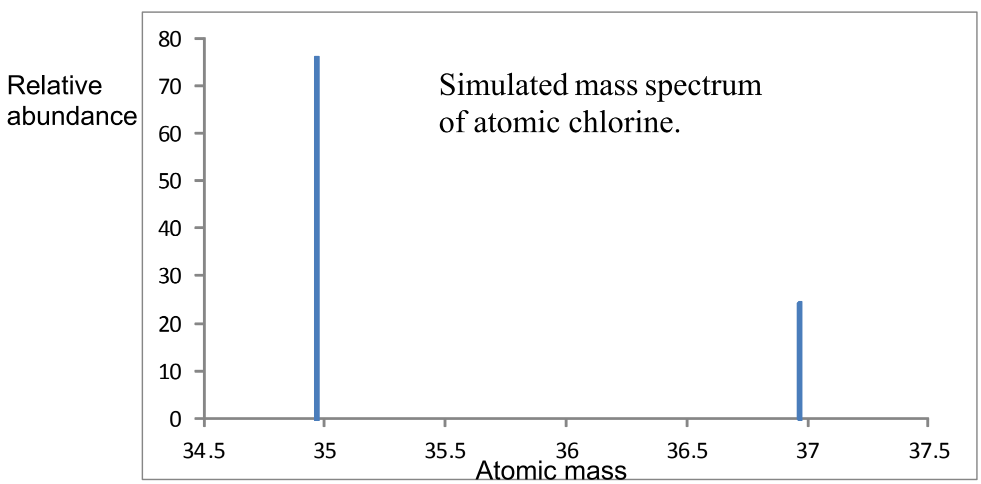

James Chadwick

Element	At. # = protons	At. Mass = protons + neutrons	#neutrons
H	1	1	0
He	2	4	2
C	6	12	6
N	7	14	7
O	8	16	8
F	9	19	10
Na	11	23	12
P	15	31	16
Ar	18	40	22
K	19	39	20
Cr	24	52	28
Bi	83	209	126
U	92	238	146
Se			
Au			

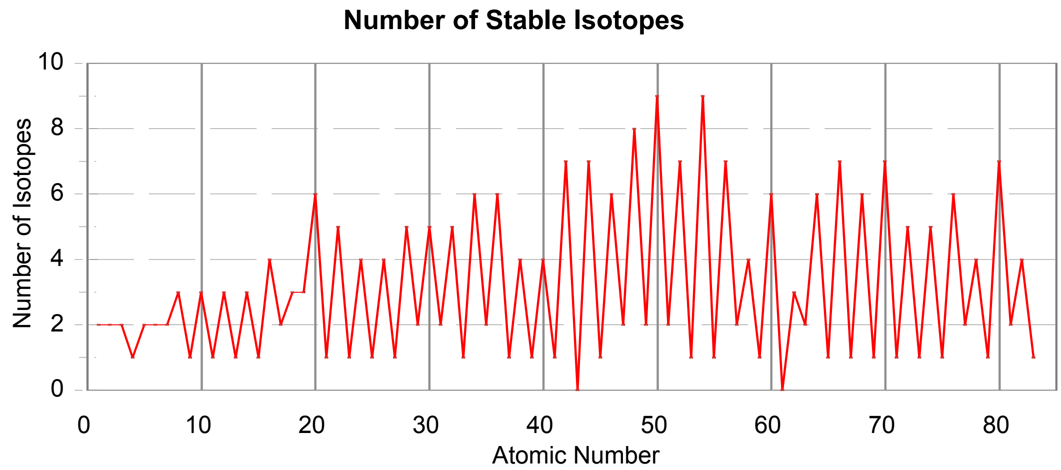
P1-1. Fill in the values for Se and Au.

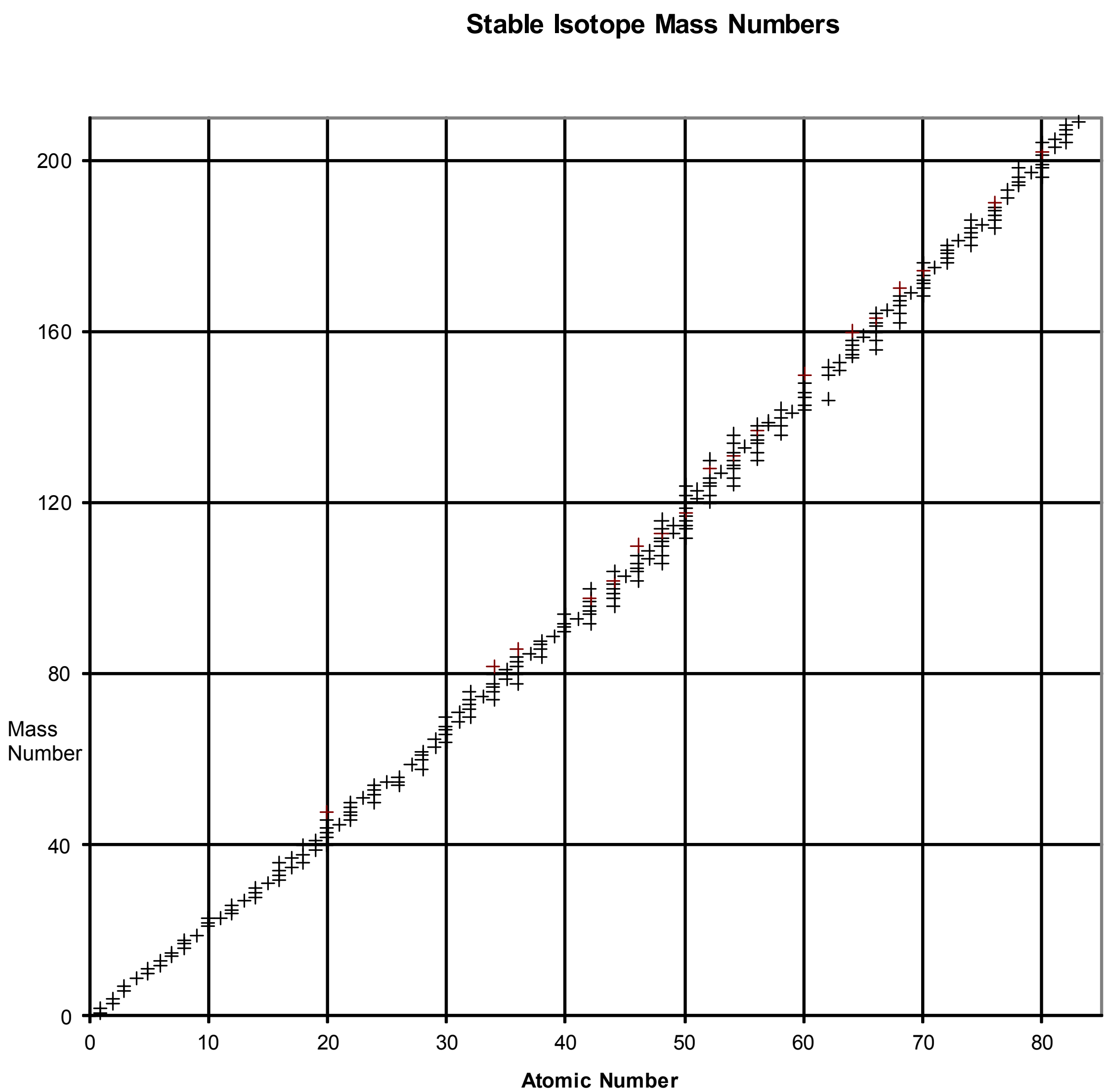
Some observations should be made. First, for the first 17 elements, the number of neutrons is close to the number of protons. In other words, each time we advance from an element to the next one by adding a proton, approximately one neutron is added. After chlorine, an average of more than one neutron is added for each proton. By the time we arrive at uranium, there are over 1.5 times as many neutrons as protons. It has been argued that the neutrons are necessary to keep the like charged protons slightly apart and the more protons there are, the greater the number of neutrons required to keep the protons apart. Second, notice that the elements were purposely chosen for the table above because they all have atomic masses that are very close to whole numbers. Many elements have atomic masses that differ significantly from whole numbers.

As an example, consider chlorine. The atomic mass for chlorine is 35.457 which is too far from a whole number to simply round off. This value leads to a value of 18.457 neutrons which is not possible as neutrons come in whole numbers only. The correct conclusion is that there are two kinds of atoms of chlorine that have different numbers of neutrons. Atoms of the same element with different numbers of neutrons are called isotopes. As a result, Dalton's atomic theory needs to be modified as he stated that atoms of one element are identical. The value of 35.457 is an experimental atomic mass determined from measurements of chlorine found on earth. From this value, it is not possible to determine which isotopes of chlorine exist without performing another experiment. A mass spectrometer is able to separate chemical species by atomic mass and a mass spectrum of chlorine shows that about 75% of chlorine atoms have 18 neutrons and the remaining 25% have 20 neutrons (see chart below). The atomic mass gives an average and does not tell you which isotopes exist. However, if the atomic mass is very close to a whole number, it is likely that the element in nature consists of primarily one isotope. Otherwise the atomic mass would only come out a whole number by coincidence. This does happen although rarely and bromine is an example. For bromine, the atomic mass of 79.9 might lead to the false conclusion that bromine has primarily one isotope with 45 neutrons when in fact it is found using a mass spectrometer that there are 2 almost equally abundant isomers with 44 and 46 neutrons. Probably most important to remember, subtraction of the atomic number from the atomic number from the atomic mass gives the **average** number of neutrons in the nucleus. **Average** needs to be included as the atomic mass alone does not give us definite information about which isotopes exist but does give us some clues.



Simulated mass spectrum of atomic chlorine.


Number of Stable Isotopes
Number of Isotopes
Atomic Number
0
2
4
6
8
10
0
10
20
30
40
50
60
70
80


Stable Isotope Mass Numbers
Mass Number
Atomic Number
0
40
80
120
160
200
0
10
20
30
40
50
60
70
80

Only certain combinations give stable atoms. Other combinations lead to unstable nucleii. An unstable combination results in radioactive decay with lifetimes of considerably different lengths depending on the amount of instability. Radioactivity will be covered in a later chapter.

The first chart above illustrates how many stable isotopes exist in nature for each element. The second chart enables you to see that on average, more than one neutron is added for each additional proton. Combinations of protons and neutrons that are not found on earth are most likely unstable and if formed in a star or supernova, have long since decayed before our present time. From a chemist's perspective, the presence of isotopes does not have tremendous significance as the **chemistry of an element is essentially independent of the number of neutrons in the nucleus**. The primary exception is that two isotopes of hydrogen are found in nature. 99.98% of hydrogen does not have a neutron in its nucleus but 0.02% does have one neutron. It is not surprising that this does affect the rates of reactions involving formation or breaking of a bond to hydrogen as the presence of the neutron **doubles** the mass of the hydrogen. For all the other elements, changes in the number of neutrons has a small percentage effect on the atomic mass and usually only a minor effect on chemical reactivity.

Besides the comments on hydrogen, it is useful to make some additional important observations from the values of atomic masses in the periodic table. It was stated that protons and neutrons have a mass of about one. Actually, the mass of a carbon isotope was used as the standard and the mass of carbon-12 was set at exactly 12. This results in masses very close to one for the proton and neutron. But in the periodic table, carbon has an atomic mass of 12.011 which indicates that while most carbon atoms have 6 protons and 6 neutrons, there must be some with more than 6 neutrons. This is a correct conclusion as the mass spectrometer reveals that 1% of carbon does contain 7 neutrons. Carbon -13 is a very useful natural component of all compounds that contain carbon especially for nuclear magnetic resonance analysis. As might be expected, carbon-14 is not stable but it is formed continually by the action of cosmic rays and is present in a small but close to constant amount of the carbon dioxide in the atmosphere. Thus despite its half life of a little over 5000 years, there is a relatively stable amount of carbon-14 in every living thing. When death results, carbon dioxide is no longer incorporated and decay of the carbon-begins. By measuring the amount of carbon-14 is a now non-living thing, it is possible to fairly accurately determine when death occurred.

1-2. Examine the number of isotopes as a function of atomic number. Is there any pattern for even vs odd atomic number values?
1-3. How would you answer the question how many protons, electrons and neutrons are present in a atom of copper?

Uranium has an atomic mass of 238.03 implying that most uranium in nature has 146 neutrons. Again, this conclusion is correct as uranium consists of 99.3% uranium-238 and 0.7% uranium-235. As there are no stable nucleii with more than 83 neutrons, all isotopes of uranium are radioactive. However, uranium-238 is only slightly unstable and has a very long half-life of 4.5 billion years. In other words, in the last 4.5 billion years, half of the uranium on earth has decayed away. This has enabled scientists to date the earth as 4.5 billion years old as the amount of uranium-238 remaining on earth is equal to the amount of its decay products. Uranium-235 is not quite as stable and has a half-life of 700 million years. Thus much more of the uranium-235 that was formed in the supernova that eventually condensed into our solar system has decayed away leaving only

0.7% of the uranium that remains. This is an extremely important piece of information as uranium-235 is fissionable and can be used in nuclear reactors and atomic bombs. Uranium-238 does not undergo fission and must be converted via an expensive process to fissionable plutonium-239 before it can be used for energy production or destruction. As the uranium that occurs on earth is primarily uranium-238, a costly and time consuming process must be used to concentrate enough uranium-235 to make it useful. It is possible to calculate that at the time the earth formed, there was abut 85 times as much uranium 235 as today. This means that the percentage of the uranium once was concentrated enough to sustain a nuclear fission reaction. There is evidence that such a sustained nuclear fission process occurred naturally in Gabon Africa about 1.7 billion years ago when the percentage of uranium-235 was still high enough to sustain a chain reaction. For more information, pleas visit the following:

http://blogs.scientificamerican.com/guest-blog/2011/07/13/natures-nuclear-reactors-the-2-billion-year-old-natural-fission-reactors-in-gabon-western-africa/
http://www.todayifoundout.com/index.php/2013/12/natural-nuclear-fission-reactor-gabon-west-africa/
http://en.wikipedia.org/wiki/Natural_nuclear_fission_reactor

In summary, all atoms are composed of three basic particles, protons, electrons and neutrons. The number of protons determines the element. While Dalton's atomic theory still is basically correct, the statements below need modification.
2. Atoms of a given element are identical in size, mass, and other properties atoms of different elements differ in size, mass, and other properties.
3. Atoms cannot be subdivided, created, or destroyed.

Dalton did not have knowledge of the make-up of atoms including the concept that many elements have nuclei with different numbers of neutrons. Thus item 2 needs to be modified to "Atoms of a given element are identical in the number of protons and electrons and other properties atoms of different elements differ in size, mass, and other properties." We also know now using nuclear means, item 3 can be violated. In addition, protons and neutrons are not absolutely basic particles as each is composed of three quarks. The nature of quarks is not needed for a discussion of chemistry but item 3 should read that atoms cannot be subdivided, reacted or destroyed by **chemical** means. Dalton himself recognized that his original part 4 of the theory needed to be modified to allow for the fact that atoms can combine in different whole-number ratios to form different chemical compounds (H_2O vs H_2O_2 or CO vs CO_2). The way it was worded above (Atoms of different elements combine in simple whole-number ratios to form chemical compounds) allows for this but the original wording implied only one combination was possible.

We have also observed that the protons and neutrons occupy a very small percentage of the volume of the atom but make up most of the mass of the atom. The electrons are in orbitals of various but describable shapes in the space outside of the nucleus. The orbitals are responsible for determining the reactivity of the elements and the shape of the periodic table. We will return to study these concepts later.

Atomic size. Atoms are extremely small. Even the strongest optical microscopes that can be built are not capable of making atoms visual. However, scanning tunneling microscopes have enabled scientists to obtain images of some of the larger atoms. For examples, visit the following:
http://factualatom.blogspot.com/2011/05/scientific-atoms.html
http://www.nobelprize.org/educational/physics/microscopes/scanning/gallery/

To gain a sense of the size of an atom, consider the number of regular sized marshmallows that would be required to cover the earth to a depth of 600 miles. Obviously this is a huge number that chemists define as a mole (simple calculations come out close to 600 sextillion or $6x10^{23}$ or a 6 with 23 zeros after it) that we shall discuss more later. It turns out that if we instead had an equal number of aluminum atoms, they would occupy a volume of only about the volume of 2 teaspoons. In other words, you would have to compact all the marshmallows 600 miles deep around the earth into 2 teaspoons to have a number of marshmallows equal to the number of aluminum atoms that would fill 2 teaspoons. This should give you the sense that atoms are truly very small.

The atom is tiny but compared to the size of the nucleus, it is huge. The nucleus has a diameter that is very roughly 30,000 times smaller than the atom. If the nucleus is imagined to be the size of a pea, then the atom is the size of a football or baseball stadium. Thinking the reverse way, if the atom were to be imagined to be the size of the earth, the nucleus would have a diameter of about a quarter of a mile. Think about the number of nuclei that would be required to fill 2 teaspoons. Looking back at the density table, you should now have a sense for the reason for the enormous density of a neutron star.

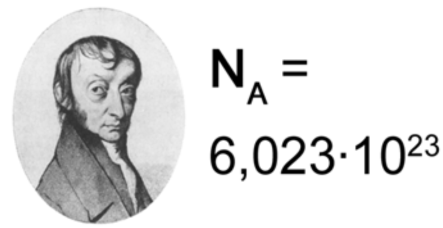
Atomic mass. Returning to the aluminum atom, an ounce (an ounce is about 28 grams and more accurately we should be talking about 27 g or the atomic mass of aluminum in the periodic table) contains a mole of atoms of aluminum or $6x10^{23}$ atoms. Using a mathematical technique called by various names including unit conversion or dimensional analysis as follows:

$$\frac{27 \text{ g Al}}{1 \text{ mole Al}} \times \frac{1 \text{ mole Al}}{6.0x10^{23} \text{ atoms Al}} = 4.5x10^{-23} \text{ g Al/atom Al}$$

The mathematical technique will be discussed later but note that the cancellation of "1 mole Al" in the numerator and denominator yields the result that an atom of Aluminum weighs 0.000000000000000000000045 g. Since an atom of aluminum contains 13 protons and 14 neutrons and these nucleons have almost the same mass, protons and neutrons must weigh approximately $4.5x10^{-23}$ g /27 or $1.7x10^{-24}$ g. This also means that an electron which weighs 1/1835 times as much as a proton weighs about $9.1x10^{-28}$ g. These tiny masses are not possible to relate to and also not possible to directly weigh on a balance. The very best balance technologically possible can only determine masses no smaller that 0.000001 or $1x10^{-6}$ g. For aluminum, this would mean that a minimum of $2.2x10^{16}$ atoms are needed for a mass measurement. Detecting that small an amount requires a vibration free environment and other restrictions that make measurements on this scale difficult. Even touching a piece of glass with your fingers typically adds about $3x10^{-4}$ g to the object. As a result, chemists work with amounts in easily measurable ranges.

The values for atomic masses in the periodic table are all relative to one another. The value of 27 for aluminum means that an aluminum atom weighs 27 times as much as a hydrogen atom, 27/12 times as much as a carbon atom and 27/238 as much as a uranium atom. If absolute values are assigned to the atomic masses, then an atom of hydrogen would have a mass of 1 atomic mass unit and aluminum 27 atomic mass units. However, as we have seen one atomic mass unit is about

$1.7x10^{-24}$ g and an impractical unit. Since the atomic masses are relative numbers, chemists decided for practical purposes to assign the term mole (derived from but not an abbreviation of molecule) to the amount of the substance when grams are attached to the atomic mass. To be more specific, carbon-12 or the isotope of carbon with 6 protons and 6 neutrons was assigned the exact mass of 12 amu on an atomic scale and 12 g on a practical gram scale. Thus if you have the gram amount of the atomic mass of any element, you will have a mole of atoms of that element. Chemists defined the mole and determined experimentally that a mole of carbon-12 atoms contain $6.022x10^{23}$ atoms. To honor the contributions of the great 19th century chemist Amedeo Avogadro, this number is now called Avogadro's number. Although some sources define the mole as Avogadro's number of atoms, this is technically not the way it was defined. It was defined as the gram equivalent of the atomic or molecular mass of a substance and Avogadro's number is a consequence of this definition.

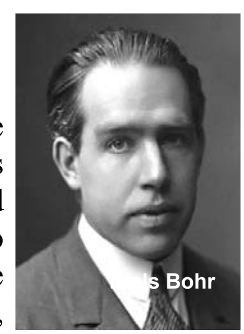


Amedeo Avogadro

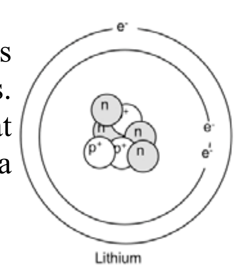
The concept of a mole is often difficult to grasp. Just as a dozen of anything would be 12 of that item, a mole of anything would be $6.022x10^{23}$ of that item. The huge value makes the number abstract but remember that a mole of marshmallows would cover the earth to a depth of 600 miles. However, a mole of carbon atoms makes the amount of carbon conveniently measurable. While the term mole could be used for anything, its use is primarily confined to chemistry. Shortly, we will need to work not only with atoms but also groups of atoms bonded together to form molecules. A mole of molecules would also contain $6.022x10^{23}$ molecules and would have a molecular mass that can be determined by adding up the atomic masses of the component atoms. For water with the formula H_2O, the molecular mass would be 1.008 + 1.008 + 15.999 = 18.015 g/mole and this many grams would contain $6.022x10^{23}$ molecules of water. The molecular mass of carbon dioxide (CO_2) would be 12.011 + 15.999 + 15.999 = 44.009 g/mole.

Determine the atomic and molecular masses (mass in grams of 1 mole of the substance):
a. Bi b. Cl_2 c. NaCl d. C_6H_6 e. $CaCO_3$ f. $Cu(NO_3)_2$

Niels Bohr



<u>Shape of the Periodic Table.</u> Mendeleev arrived at the shape of the periodic table by arranging the elements according to increasing atomic mass (today it is atomic number) and starting new rows to make reactivities and formulas line up as best as possible. It is now time to probe this issue further to determine if we can find a reason on the atomic scale for the shape of the periodic table. While the element is determined by the number of protons, chemistry does not involve any changes in the nucleus. During chemical reactions, only the role of electrons change. Chemical reactions result in electrons being lost (oxidation), gained (reduction) or shared with other atoms. Historically, after the discovery of the electron and protons, scientists realized that Bohr's solar system model for the atom was not correct and began a search for a much better model for the electronic structure of atoms.



Bohr model of Lithium (Li)

I. Traditional PERIODIC TABLE OF THE ELEMENTS

s		d										p					
1 *1A*	2 *2A*	3 *3B*	4 *4B*	5 *5B*	6 *6B*	7 *7B*	8 *8B*	9 *8B*	10 *8B*	11 *1B*	12 *2B*	13 *3A*	14 *4A*	15 *5A*	16 *6A*	17 *7A*	18 *8A*
1 ***H*** 1.008																	2 ***He*** 4.0026
3 **Li** 6.97	4 **Be** 9.012											5 **B** 10.82	6 **C** 12.011	7 ***N*** 14.007	8 ***O*** 15.999	9 ***F*** 18.998	10 ***Ne*** 20.180
11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.07	17 ***Cl*** 35.45	18 ***Ar*** 39.948
19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.847	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.63	33 **As** 74.922	34 **Se** 78.96	35 Br 79.904	36 ***Kr*** 83.798
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.94	43 Tc (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 ***Xe*** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 Hg 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 Po (209)	85 At (210)	86 *Rn* (222)
87 Fr (223)	88 Ra 226.03	89 Ac 227.03	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Ds (269)	111 Rg (272)	112 Cn (277)	113 2003 (284)	114 Fr (289)	115 2003 (288)	116 Lv (292)	117 2010 (294)	118 2006 (294)

f

58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 Pm (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

key: bold or normal italics - gas, shadow - liquid, bold or normal - solid, normal print - all known isotopes are radioactive

II. PERIODIC TABLE OF ELEMENTS FOUND IN ELEMENTAL FORM

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 rarely ☺	81 Tl	82 Pb ☺	83 Bi ? ☺	84 Po	85 At	86 Rn ☺
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 2003	114 Fl	115 2003	116 Lv	117 2010	118 2006

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

III. PERIODIC TABLE OF THE ELEMENTS - Date and Country of Discovery

s | d | p | f

- before 1700
- 1700 - 1799
- 1800 - 1849
- 1850 - 1899
- 1900 - 1949
- 1950 - 1999
- 2000 - present

1 *1A*	2 *2A*	3 *3B*	4 *4B*	5 *5B*	6 *6B*	7 *7B*	8 *8B*	9 *8B*	10 *8B*	11 *1B*	12 *2B*	13 *3A*	14 *4A*	15 *5A*	16 *6A*	17 *7A*	18 *8A*
																	2 ***He*** 1895 UK
3 **Li** 1817 SE	4 **Be** 1798 FR										1808 1	5 **B** ancient	6 **C** 1772 UK	7 ***N*** 1774 2	8 ***O*** 1886 FR	9 ***F*** 1898 UK	10 ***Ne***
11 **Na** 1807 UK	12 **Mg** 1755 UK											13 **Al** 1825 DK	14 **Si** 1824 SE	15 **P** 1869 DE	16 **S** ancient	17 ***Cl*** 1774 SE	18 ***Ar*** 1894 UK
19 **K** 1807 UK	20 **Ca** 1808 UK	21 **Sc** 1879 SE	22 **Ti** 1791 UK	23 **V** 1801 3	24 **Cr** 1797 FR	25 **Mn** 1774 SE	26 **Fe** ancient	27 **Co** 1735 SE	28 **Ni** 1751 SE	29 **Cu** ancient	30 **Zn** 1746 DE	31 **Ga** 1875 FR	32 **Ge** 1886 DE	33 **As** ancient	34 **Se** 1817 SE	35 Br 1826 FR	36 ***Kr*** 1898 UK
37 **Rb** 1861 DE	38 **Sr** 1790 UK	39 **Y** 1794 FI	40 **Zr** 1789 DE	41 **Nb** 1801 UK	42 **Mo** 1781 SE	43 Tc 1937 IT	44 **Ru** 1844 RU	45 **Rh** 1803 UK	46 **Pd** 1803 UK	47 **Ag** ancient	48 **Cd** 1817 DE	49 **In** 1863 DE	50 **Sn** ancient	51 **Sb** ancient	52 **Te** 1783 RO	53 **I** 1811 FR	54 ***Xe*** 1898 UK
55 **Cs** 1860 DE	56 **Ba** 1808 UK	57 **La** 1839 SE	72 **Hf** 1923 DK	73 **Ta** 1802 SE	74 **W** 1783 ES	75 **Re** 1925 DE	76 **Os** 1803 UK	77 **Ir** 1803 1	78 **Pt** 1735 CO	79 **Au** ancient	80 Hg ancient	81 **Tl** 1861 UK	82 **Pb** ancient	83 **Bi** ancient	84 Po 1898 FR	85 At 1949 US	86 *Rn* 1900 DE
87 Fr 1939 FR	88 Ra 1898 FR	89 Ac 1899 FR	104 Rf 1964 6	105 Db 1967 6	106 Sg 1974 US	107 Bh 1981 DE	108 Hs 1984 US	109 Mt 1982 DE	110 Ds 1994 DE	111 Rg 1994 DE	112 Cn 1996 DE	113 Uut 2003 RU	114 Fr 1998 RU	115 Uup 2003 RU	116 Lv 2000 RU	117 Uus 2010 6	118 Uuo 2006 6
			58 **Ce** 1803 SE	59 **Pr** 1885 AT	60 **Nd** 1885 AT	61 Pm 1945 US	62 **Sm** 1879 FR	63 **Eu** 1901 FR	64 **Gd** 1880 CH	65 **Tb** 1843 SE	66 **Dy** 1886 FR	67 **Ho** 1878 CH	68 **Er** 1842 SE	69 **Tm** 1879 SE	70 **Yb** 1878 CH	71 **Lu** 1907 FR	
			90 Th 1829 SE	91 Pa 1913 4	92 U 1789 DE	93 Np 1940 US	94 Pu 1940 US	95 Am 1944 US	96 Cm 1944 US	97 Bk 1949 US	98 Cf 1950 US	99 Es 1952 US	100 Fm 1952 US	101 Md 1955 US	102 No 1961 5	103 Lr 1961 US	