Atomic Theory – A Little History

This page chronicles 2500 years of history in the blink of an eye. Most of what we know about the structure of the atom itself has been discovered in the last 200 years of that 2500 year span. Nevertheless, our modern understanding of the atom rests upon the foundation laid by those "pioneers" who worked to understand the nature and behavior of matter with little more than keen observation skills and common sense.

Earliest Theories

The earliest Greek philosophers thought that all the different things in the world were made out of a single basic substance. Some thought that water was the fundamental substance and that all other substances were derived from it. Others thought that air was the basic substance; still others favored fire. But neither water, nor air nor fire was satisfactory. No one substance seemed to have enough different properties to give rise to the enormous variety of substances in the world. According to another view introduced by Empedocles around 450 B.C., there were four basic types of matter- earth, air, fire, and water. All material things were made out of them. He proposed that these four basic materials could mingle and separate and reunite in different proportions. By doing so they could produce the vast variety of familiar objects around us as well as explain the changes in those objects. But the basic four materials, called **elements**, were supposed to persist through all these changes. This theory was the first appearance of a model of matter explaining all material things as just different arrangements of a few elements.

The first atomic theory of matter was introduced by the Greek philosopher Leucippus, born about 500 B.C. and his pupil Democritus. Only scattered fragments of the writings of these two philosophers remain. But their ideas were discussed in considerable detail by the Greek philosophers Aristotle and Epicurus, and later by the Latin poet Lucretius. To these men we owe most of our knowledge of ancient atomism. The theory of the atomists was based on the following assumptions:

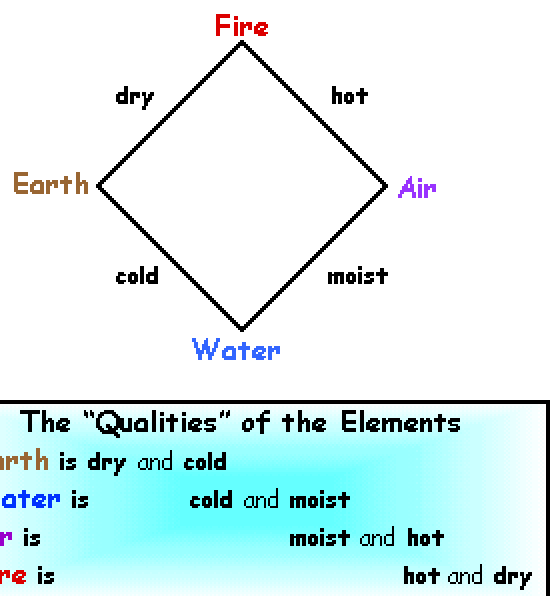
1. **Matter is eternal -** no material thing can come from nothing, nor can any material thing pass into nothing.
2. Material things consist of very small indivisible particles. The word **atom meant "uncuttable"** in Greek.
3. Atoms differ chiefly in their sizes and shapes.
4. Atoms exist in otherwise **empty space (the void)** which separates them, and this space allows them to move from one place to another.
5. **Atoms are continually in motion**, although the nature and cause of the motion are not clear.
6. In the course of their motions atoms come together and **form combinations** which are the material substances we know. When the atoms forming these combinations separate, the substances decay or break up. Thus, the combinations and separations of atoms give rise to the changes which take place in the world.
7. The combinations and separations take place according to natural laws which are not yet clear, **but do not require the action of gods or demons or other supernatural powers**. In fact, one of the chief aims of the atomists was to liberate people from superstition and

fear. With these assumptions, the ancient atomists worked out a consistent story of change, which they sometimes called "coming-to-be" and "passing away". They could not demonstrate experimentally that their theory was correct - it was simply an explanation derived from assumptions that seemed reasonable to them.

The atomic theory was severely criticized by Aristotle. He argued logically - from his own assumptions - that no vacuum or void could exist. Therefore, the idea of atoms in continual motion must be rejected. He was also probably aware of the fact that in his time belief in atomism was identified with atheism as it stated that gods were unnecessary - not a very healthy view in 450 B.C.

Aristotle's Theory

Aristotle developed a theory of matter as part of his grand scheme of the universe. This theory, with some modifications, was considered satisfactory by most philosophers of nature for nearly two thousand years. It was based on the four basic elements, Earth, Air, Fire and Water, and four "qualities", Cold, Hot, Moist, and Dry. Each element was characterized by two qualities (the nearer two to each side as shown in the diagram).



In Aristotle's version, the elements are not unchangeable. Any one of them may be transformed into any other if one or both of its qualities change to their opposites. The transformation takes place most easily between two elements having one quality in common. Thus Earth is transformed into Water when dryness changes into moistness, and so on.

Aristotle was able to explain many natural phenomena by means of his ideas. Like the atomic theory, Aristotle's theory of coming-to-be and passing-away was a consistent model of the nature of matter. And it had certain advantages over the atomic theory. For example, it was based on elements and qualities that were familiar to people; it did not involve atoms, which could not be seen or otherwise perceived, or a void, which was difficult to imagine. It seemed to supply a rational basis for the fascinating possibility of changing any material into any other.

100 B.C - 1400 B.C. The Alchemists

300 or 400 years after Aristotle, a kind of research called alchemy appeared in the Near and Far East. Alchemists combined Aristotle's ideas about matter with methods of treating ores and metals. One aim of the alchemists was to change or "transmute" ordinary metals into precious metals like gold. Although they failed to do this, the alchemists found and studied many properties that are now classified as chemical properties. They invented some pieces of chemical apparatus, such as reaction vessels and distillation flasks that are still commonly used in chemistry labs today. They studied such processes as calcination, distillation, fermentation, and sublimation. In this sense alchemy may be regarded as the chemistry of the Middle Ages, but it left unsolved all the fundamental questions.

1. What is a chemical element?
2. What is the nature of chemical composition and chemical change, especially burning.
3. What is the chemical nature of the so-called elements, Earth, Air, Fire and Water?

Until these questions were answered it was impossible to make real progress in finding out the structure of matter.

A Review of Atomic Structure

1600 - 1700's

During the seventeenth century some forward steps were made, supplying a basis for future progress on the problem of matter. The works of Copernicus, Galileo and Newton greatly undermined the authority of Aristotle. His ideas about matter were questioned. Atomic concepts were revived, offering a way of looking at things that was very different from Aristotle's ideas. As a result theories involving atoms were again considered seriously. Boyle based his model on the idea of gas "particles". Newton also discussed the behavior of a gas and even of light by supposing it to consist of particles. The stage was set for a general revival of atomic theory.

1700 - 1800's Laws of Chemical Combination

Chemistry became more quantitative. Weighing, in particular, was done more frequently and more carefully. New substances were isolated and their properties examined. The attitude that grew up in the second half of the century was apparent in the work of Henry Cavendish (1731 - 1810). According to a biographer, Cavendish regarded the universe as consisting

> ...solely of a multitude of objects which could be weighed, numbered, and measured; and the vocation to which he considered himself called was to weigh, number, and measure as many of those objects as his allotted threescore years and ten would permit... He weighed the Earth; he analyzed the Air; he discovered the compound nature of Water; he noted with numerical precision the obscure action of the ancient element Fire.

Eighteenth century chemistry reached its peak in the work of Antoine Lavoisier (1743 - 1794).   He worked out the modern views of combustion, established the Law of conservation of mass, and explained the elementary nature of hydrogen and oxygen and the composition of water.

During the second half of the eighteenth century and the early years of the nineteenth century great progress was made in chemistry. This progress resulted largely from the increasing use of quantitative methods. Chemists found out more and more about the composition of substances. They separated many elements and showed that nearly all substances are compounds - combinations of a fairly small number of chemical elements. They learned a great deal about how elements combine and form compounds and how compounds can be broken down into the elements of which they consist. This information allowed chemists to establish many empirical laws of chemical combination. What were these Laws of Chemical Change?

1. **Law of Conservation of Mass** - matter can be neither created nor destroyed
2. **Law of Definite Proportions** - Elements combine to form compounds in fixed proportions by weight.

3. **Law of Multiple Proportions** - When two elements combine to form more than one compound, the mass of the second element that combines with a fixed quantity of the first element are in the ratio of small whole numbers.
4. **Law of Combining Volumes** - When gases react, they do so in simple whole number ratios by volume.

What is significant here is the fact that according to all the Laws of Chemical Combination, matter behaves as though it were made up of particles. This is the only conclusion that is reasonable given that the Laws make continual reference to fixed proportions, small whole numbers, and whole number ratios.

1800 - 1850 A New Atomic Theory

Prior to 1800, the particle nature of matter was based largely on intuition. However, during the first ten years of the nineteenth century, the English chemist (and school teacher) John Dalton introduced a modified form of the old Greek atomic theory. Dalton's theory was an attempt to account for the laws of chemical combination mentioned above. It is here that the modern story of the atom begins. Dalton's atomic theory was an improvement over that of the Greeks because it opened the way for quantitative study of the atom. Today the existence of the atom is no longer a topic of speculation. There are many kinds of experimental evidence, not only for the existence of atoms but also for their inner structure. We will now trace a few of the discoveries and ideas that provided this evidence.

Dalton's Atomic Theory

Dalton's Theory consisted of 5 main points:

1. All matter consists of individual indivisible particles or "atoms."
2. Each element consists of a characteristic kind of identical atom which are alike in every respect, especially mass.
3. Atoms cannot be divided into smaller parts
4. Atoms of elements combine to form different compounds in definite proportions.
5. In chemical reactions, atoms are neither created nor destroyed, only rearranged.

Dalton's theory was not original. As you can see, it is actually a modified version of the early Greek atomist’s theory, but with 2000 years of accumulated experimental evidence to support it.

From this point forward, science has accepted that since large quantities of matter behave as though it were made up of particles, it must indeed be made up of particles.

What next??

Like most scientific theories, the atomic theory raised more questions than it answered. Scientists immediately wondered if these tiny little particles called atoms could be broken down into still smaller particles. It took well over 100 years to find out and work out the details.

A Quick Look at Modern Atomic Theory

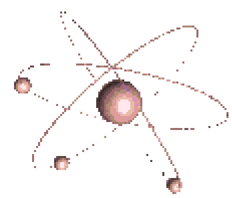
In your previous science courses, you learned a number of the key discoveries that have led to our present understanding of the structure of the atom, and the nature of matter. It was a long slow process, where each new understanding was based on some prior knowledge. So, what are atoms made of? This brief review is intended to answer that question.

Three scientists did pioneer work in this area.

1. J.J. Thomson is credited with discovering and naming the *electron* in 1897.
2. Robert Millikan is credited with determining the unit *charge* on the electron. (-1)
3. Ernest Rutherford is credited with the discovery that atoms contain a small, positively charged, massive center called the atomic nucleus which contains almost all the mass of the atom. He also showed that the diameter of the nucleus (about 10^{-5} nm) is only 1/10000 of the diameter of the atom. The atom as a whole therefore, is mostly empty space!!

We have since learned that the nucleus of an atom consists of two different types of particles.

1. The **proton** which carries a unit positive charge (+1) and has a relative mass of 1.00 atomic mass units and is approximately equal to the mass of a hydrogen atom (which is the lightest element known).



2. The **neutron**, an uncharged particle with a mass about equal to that of a proton was discovered in 1932. Like the proton, the neutron has a relative mass of one atomic mass unit (a.m.u.).

The following chart summarizes the properties of the sub atomic particles which make up an atom. The relative masses and charges of the particles are used here, rather than their actual values.

Particle Name	Symbol	Relative Charge	Relative mass	Location in the Atom
electron	e^-	-1	1/1840 mass of a proton	extra nuclear region
proton	p^+	+1	1.00 a.m.u.	in the nucleus
neutron	n^o	0	1.00 a.m.u.	in the nucleus

By 1900, scientists had begun to speculate on the way in which positive and negative charges are arranged in atoms.

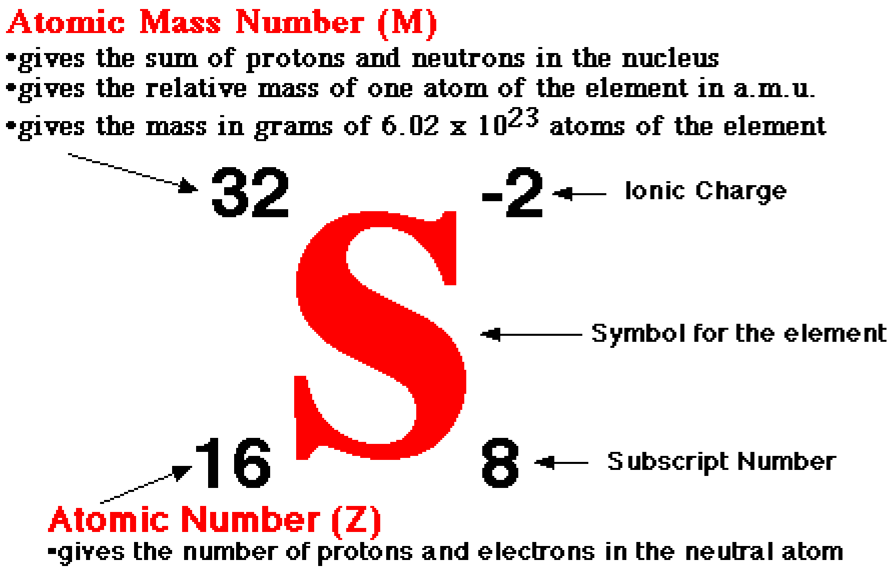
"Models" of the Atom

A number of "models" were proposed which attempted to describe how all the parts and pieces of the atom fit together. Do you remember the "plum pudding" model proposed by J.J. Thomson, followed by the "nuclear" model proposed about 1911 by Ernest Rutherford? Check your textbook for information on these concepts.

The last question that needs answering is "exactly where are each of the electrons in the extra-nuclear region?" That question was in large part answered by Neils Bohr who developed a model for the behavior of electrons in the hydrogen atom. He postulated that electrons could exist only in certain "regions" about the nucleus. His model of the atom is not surprisingly called the Bohr Model of the atom, if you need a review of the Bohr Model please read pages 60-61 in your Nelson Chemistry textbook.

A Summary

Information about the number of protons, neutrons and electrons in any given atom is given in the Periodic Table. The organization of that information is usually presented in the following format, the diagram below along with the notes which follow it, summarize this information using the element sulphur as a representative example:



Here is a brief description of each of the important terms in the diagram:

The Atomic Number

All the atoms of a particular element have the same number of protons in the nucleus. The number of protons in the nucleus of an atom is therefore the "signature number" for that element. For example, every atom of sulfur in the universe will have exactly 16 protons in its nucleus. If it didn't, it would not be sulfur. It would be a different element altogether. Similarly, every hydrogen atom has one proton, every oxygen atom has 8 protons and so on. The number of protons in the nucleus of an atom is called the atomic number.

atomic number = number of protons

If the atom is neutral, the number of protons is exactly equal to the number of electrons orbiting the nucleus in the extra nuclear region. For example, a neutral oxygen atom has 8 protons (+8 in total) and 8 electrons (-8 in total), for a net overall charge of 0.

The Atomic Mass Number

It should make sense that the mass of an atom is the sum of the masses of the particles making it up. Since the mass of a proton and the mass of a neutron is about the same (1.00 a.m.u.) the relative mass of an atom can be obtained by adding up the number of protons and neutrons in the nucleus. The mass of the electron is so small that its contribution to the mass of the atom is considered negligible.

atomic mass number = number of protons + number of neutrons

The Ionic Charge

If a neutral atom accepts or loses electrons, it takes on a charge. (Detailed notes on ion formation will follow shortly). The information about what charge, or valence, the resulting ion has is indicated by a number and a sign in the upper right hand corner of the symbol.

The Subscript Number

This number, located at the bottom right hand corner of the symbol, tells you how many atoms of that type are present in a molecule, ion or ionic compound. For example, in the formula H_2SO_4, there are two hydrogen atoms, one sulfur atom and four oxygen atoms in the sulfuric acid molecule. The formula S_8 indicates that there are 8 atoms of sulfur in a molecule of sulfur.

Molecules and Ions

Only a few elements exist as free atoms in nature. Most elements and all compounds are built up of more complex structural units, and two of the most important of these are **molecules** and **ions**. The details of how these are formed are the basis of the Bonding Unit of Chemistry 20, but there are a few points you should know now.

Molecules - The basic structural unit of many substances is the molecule. A molecule is a neutral group of two or more atoms held together by strong forces of attraction called chemical bonds. There will be more about these later.

Ions and Ion Formation

Charged particles (atoms or clusters of atoms with positive or negative charge) are called ions. The number of electrons that an atom will lose or gain in order to become an ion can be predicted by remembering one important point. Recall from Science 10 that the Noble gases are the most stable, (therefore the least reactive) elements on the periodic table. What is it about the Noble gases that makes them so stable? It turns out that there is something "unique" about the number of electrons that the noble gases possess. Because they have the number of electrons they do, each noble gas has a full outer energy level, and it is that full outer energy level that results in exceptional stability. Every other element in the periodic table would also like to have a full outer energy level, so they will spontaneous lose or gain whatever number of electrons is necessary to achieve this. Metals tend to lose electrons while non-metals tend to gain electrons in order to achieve the desired electron number. Here is the formal statement you learned from Science 10:

Atoms will gain or lose electrons in order to become isoelectronic with their nearest noble gas, and thus become more stable. (Isoelectronic means "the atoms will have the same number of electrons").

Here are the details:

If sufficient energy is applied to a neutral metallic atom, it can be used to remove one or more electrons from that atom. The metallic atom, having lost electrons will form a positively charged particle which will be slightly smaller in diameter than the neutral atom from which it was formed. Particles that carry a positive charge are called **cations**. The formation of a cation is exemplified by the formation of a sodium ion (Na^+) as a neutral atom of sodium loses a single electron to obtain the same number of electrons as the noble gas neon.

Na^o atom -------> Na^+ ion + $1e^-$
$11p^+$ $11p^+$
$11e^-$ $10\ e^-$ (like Neon)

Notice that when an ion is formed, the number of protons in the nucleus does not change. Only the electron number changes.

In a similar fashion, electrons may be added to non-metallic atoms resulting in a negatively charged particle slightly larger in diameter than the neutral atom from which it was formed. Particles that carry a negative charge are called **anions**. The first three letters of the word "anion" can be used as a reminder that anions are negative ions. One common negative ion is the chloride ion (Cl^-).

Cl^o atom + $1\ e^-$ -------> Cl^- ion
$17p^+$ $17p^+$
$17e^-$ $18\ e^-$ (like Argon)

As you already know from the study of nomenclature, and as you will find again in the bonding unit, many compounds are made up of ions. They are called ionic compounds. A good example is sodium chloride (table salt) which is made up of equal numbers of sodium ions and chloride ions in a lattice structure called a crystal.