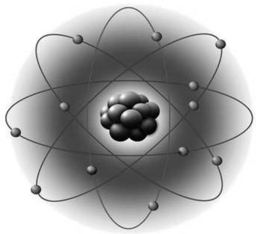
The Atom and the Subatomic Particles



The purpose of this handout is to familiarize the chemistry student with the history, development and structure of the atomic model. In the hope, that the student will better understand the role of the **electron**. If one is to understand the basics of chemistry, one must understand that it is the **electron** and the electron configuration that determines chemical bonding, chemical formation and chemical reactivity.

So, there are three questions we must answer:

1. What is the electron?
2. Where is the electron?
3. How does the electron behave?

Learn the answer to these questions and chemistry is no longer magical, but practical.

DEVELOPMENT OF ATOMIC MODELS

Scientific Models

It is important to bear in mind that science is at its best when it **describes** how things work, but gets into trouble when it tries to tell why natural phenomena occur. As long as we understand that scientists are describing what they observe as workable and not explaining why it is true; we avoid problems.

Also, we must remember that scientists are unable to work with all natural phenomena directly. So, chemists, physicists and even biologists need to create **models** to help describe natural phenomena that they are unable to work with directly. But, a scientific model is **limited** to the information available at the time it is created and much of this evidence is obtained indirectly. In other words, the evidence itself is obtained from models and models are only as good as the evidence. Therefore, when new ideas give rise to new experiments that lead to new discoveries the <u>model must be changed</u> or discarded. This process of discovery is real science at its best.

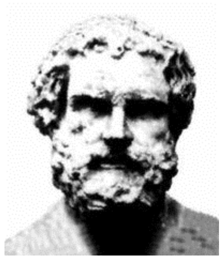
Although, scientific models change, models are the only way man has to describe how several natural phenomena work. And knowing how a process functions is often crucial to further scientific discovery. So, remember <u>models are not truth</u>, models are scientists' best description of how things work not why things work. For this reason, the importance of models is not their truth, but their **workability**.

Six Basic Atomic Models

The *Quantum Mechanical Model* of the atom that we use today did not develop through the work of one man. It has evolved through the work of many men over several years. Each man or group of men was building on the work of the previous in an effort to build a **workable** model of the atom.

- Solid Sphere Model
- Plum Pudding Model
- Nuclear Model (Rutherford)
- Planetary Model (Bohr)
- Wave Mechanical Model
- Quantum Mechanical Model

In the Beginning



The idea that matter consists of small particles is as old as the ancient Greeks. Democritus (460 -370 BC) and Leucippus, disagreeing with Aristotle, proposed that all materials were made of tiny particles called **atomos** meaning "indivisible".

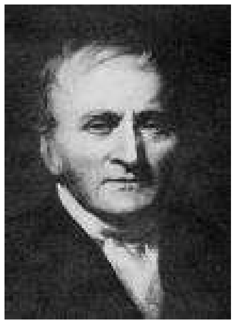
The atomists believed that material things consist of an infinite number of very small particles that are not physically but geometrically indivisible. But, the Greeks never performed any experiments to test the workability of their ideas and Aristotle's "non-atomic" view of material won out over the atomists. Therefore, the development of the

Democritus

atomic model went undiscovered until the modern scientific revolution.

"By convention there is sweet, by convention there is bitterness, by convention hot and cold, by convention color; but in reality there are only atoms and the void."
- Democritus

SOLID SPHERE MODEL



By the early 1800's, the Law of Definite Composition and the Law of Multiple Proportions were commonly accepted ideas concerning the behavior of matter.

- **Law of Definite Composition** states that in any sample of a compound the masses of the elements are in the same ratio.
- **Law of Multiple Proportions** states that when two elements combine to form more than one compound, the fixed amounts of one element will combine with the other in a ratio of small whole numbers

John Dalton

Influenced by these concepts **John Dalton**, a Quaker school teacher, took these ideas and the work of others and devised the first atomic model based on **empirical** evidence. In 1808, John Dalton introduced his atomic theory to the world in his first volume of *New System of Chemical Philosophy.*

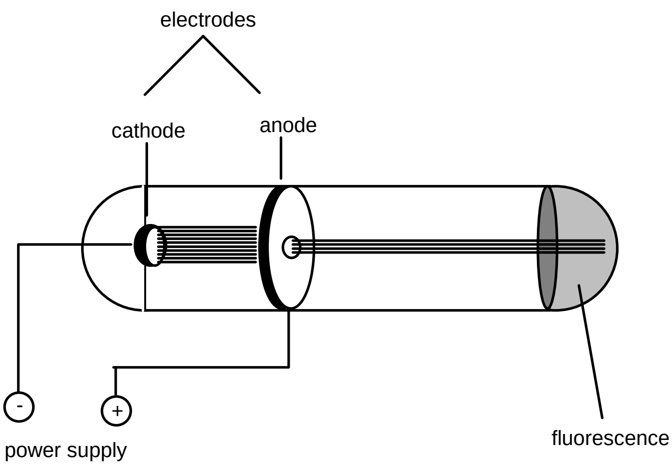
Dalton's Postulates

1. All matter consists of tiny, indivisible, indestructible particles called atoms.
2. Atoms of the same element have the same size, mass and chemical properties.
3. Differences in the properties of elements result from differences in the atoms of the elements.
4. The atoms in a compound combine in a definite, simple, whole number ratio.
5. A chemical reaction is the result of rearrangement, combination, or separation of atoms.

"We might as well attempt to introduce a new planet into the solar system or to annihilate one already in existence, as to create or destroy a particle of hydrogen."
– John Dalton

PLUM PUDDING MODEL

In 1859 the German physicist, **Julius Plucker**, developed a vacuum tube that allowed a current to flow across a gap from the **cathode (-)** to the **anode (+)**. **Eugene Goldstein** realized this was a type of radiation and named the new radiation **cathode rays**. Thus the cathode ray tube (CRT) was born, and would eventually lead to the development of radio, television and computers.



cathode ray tube (CRT)

Later in 1879, English physicist **Sir William Crookes** proposed that cathode rays were actually streams of particles flowing from the cathode to the anode, and these particles had the same properties regardless of the cathode material used to produce the cathode rays.

Then in 1891, Irish physicist **George Stoney** proposed that a negatively charged particle associated with the atom existed, and he suggested the new particle be called an **electron**. Stoney derived this name from the Greek word "elektron" meaning amber-- a substance known to become electrically charged. However, he was unable to prove the existence of this particle.

Soon after in 1897, English physicist, **J. J. Thomson** performed a set of experiments that showed cathode rays could be deflected away from a negative charge by both electric and magnetic fields. This discovery led Thomson to suggest that cathode rays are negatively charged particles which he called corpuscles (electrons). Thomson then determined the corpuscle's charge to mass ratio (e/m).

J.J. Thomson

"I can see no escape from the conclusion that [cathode rays] are charges of negative electricity carried by particles of matter."
– J.J. Thomson

Robert Millikan

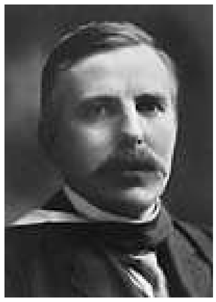
Finally in 1909, American physicist **Robert Millikan** performed his now famous **Oil Drop** experiment that confirmed the actual charge of the electron. Using Millikan's findings and the charge to mass ratio, Thomson calculated the mass of the negatively charged corpuscle.

The electron was no longer an idea but a real particle, but its mass is 1836 times smaller than the hydrogen ion, the smallest known ion. Thus, the electron is just a small part of the atom, in other words the electron was a subatomic particle. Dalton's theory of an indivisible particle was no longer acceptable. Now, a theory that allowed for subatomic particles was needed.

"I was told long afterwards by a distinguished physicist who had been present at my lecture that he thought I had been pulling their leg." -J. J. Thomson

Thomson proposed that the atom was a mass of positive charge with negative electrons embedded into it like raisins in a pudding, so it was dubbed the **Plum Pudding** model. Thomson's Plum Pudding model, although attractive, was short lived. **Philipp Lenard** had noted that cathode rays could pass through very thin pieces of matter. Thus, in 1903, Lenard suggested that the atom was not a large positively charged mass but mostly space.

NUCLEAR ATOMIC MODEL



New Zealand born, **Ernest Rutherford** had his assistants Hans Geiger and Ernest Marsden put the *Plum-Pudding* model to the test. In 1909, Geiger and Marsden performed the famous **Gold Foil** experiment that led to the discoveries of the atomic nucleus and that the atom was mostly space.

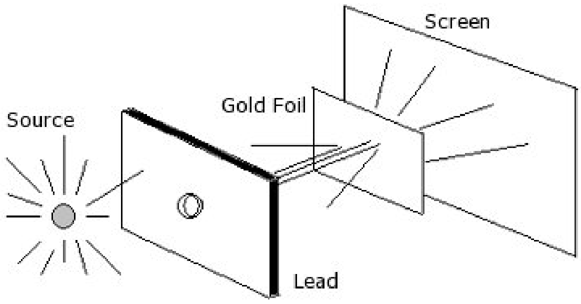
Geiger and Marsden set up an experiment to determine the effect of bombarding a thin sheet of gold foil with rays from a radioactive source such as radium. They cut a small hole in a lead plate so that the stream of rays could be focused. Then they placed a thin sheet of gold foil and a viewing screen on the other side of the hole as shown in the diagram.

Ernest Rutherford

The flashes of light produced when alpha particles strike the zinc sulfide screen can be observed through a movable microscope. Most of the alpha particles passed through the gold foil undeflected, but a few were deflected back toward the source.

The *Gold Foil* experiment demonstrated that the mass of the atom was the same as predicted by Thompson's model, but the volume of the mass was much smaller and seemed to be located in the center of the atom. This massive center known today as the **atomic nucleus** has a volume one trillionth the volume of the whole atom.

Thompson's *Plum Pudding* model was no longer workable. So, in 911, Rutherford proposed the **Nuclear Atomic Model**.

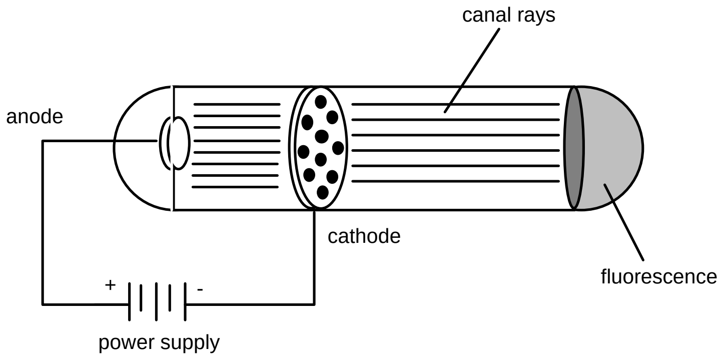


Gold Foil Experiment

Rutherford's new model stated that the atom was mostly empty space with a small, very dense positively charged nucleus surrounded by negatively charged electrons located in the atomic space. But, how did the nucleus obtain its positive charge?

THE PROTON

Further studies with the cathode ray tube lead Eugene Goldstein to the discovery of rays that flowed in the opposite direction of the cathode rays. These new rays were called **canal rays** because they flowed through canals in the cathode. The canal rays were thought to be positively charged because they flowed opposite of the cathode rays. Knowing that the atom is electrically neutral and the electron has almost no mass, Goldstein suggested that a positively



canal ray tube

charged particle must exist in order to balance the negatively charged electron and account for the mass of the atom. Soon **Wilhelm Wien** and J. J. Thomson determined the charge to mass ratio (e/m) of the canal ray. Then, using the positive equivalent of the electron charge, the mass of the canal ray particle was determined to be 1836 times the mass of the electron. This was roughly the mass of the common hydrogen ion. In 1918 Rutherford suggested the particle (hydrogen ion) be called a **proton**.

The Atomic Number

Henry Moseley

In 1913, English physicist **Henry Moseley** observed the properties of **x-rays** from about a dozen consecutive elements in the periodic table. In doing so, he discovered that the **wavelength** of the x-rays became shorter as the atomic weight increased. This meant that both the **frequency** and **energy** were increasing because of the inverse relationship between wavelength and frequency. By taking the square root of the frequency, Moseley found that the increase was constant from one element to the next. Moseley suggested that this regular increase from element to element must be caused by *something* in the atom. He then showed that this *something* was the positive charge (protons) in the nucleus. Moseley referred to this positive charge collectively as the **atomic number.**

The new concept of the atomic number brought even more power to the periodic table. Instead of the elements being arranged by relative atomic masses, elements could now be arranged by atomic numbers without one element out of order. Now, for the first time scientist could tell how many elements remained to be discovered because of the numerical gaps. It was also obvious that it is the number of protons that determine which element is which and not the electrons or other particles. Moseley had truly made a great discovery.

The discovery of the nuclear charge (atomic number) also resulted in being able to determine the number of electrons in an atom. It was previously known, that a neutral atom must have just enough electrons to neutralize the positive nuclear charge and if an atom lost or gained electrons it would become a charged atom (ion). Therefore, **in a neutral atom the number of electrons must equal the number of protons.**

The Neutron

James Chadwick

The discovery of not one but two subatomic particles required the rewriting of Rutherford’s model to include the proton. But the proton did not account for all the mass of the nucleus. Thus, scientists believed there was another particle similar to the proton but neutrally charged.

In 1920, Rutherford suggested the existence of another subatomic particle to account for the difference between the mass of the nucleus and the mass of the protons. Rutherford believed the new particle would have the mass of a hydrogen atom (proton) and a neutral charge. But, because of the neutral charge the particle would be hard to isolate. Then in 1930 a new radiation was observed. It was very penetrating, unaffected by a magnetic field, and could not be detected directly. However, when a substance was placed in the way of the radiation, protons were thrown out of the substance.

James Chadwick, in 1932, explained that a proton could not be pushed around so easily by electrons, but had to be moved by a massive particle like the proton. Thus, it was determined the new radiation was the particle that Rutherford had predicted and because its charge was neutral, it was named the **neutron**.

A Look at History

Rutherford was Thomson's student at one time and he came upon his discovery in an attempt to justify his teacher's theory. However in the process of justifying the Plum Pudding model, new information led Rutherford to disagree with the Plum Pudding model and he set out to create his own model.

Nobel Medal

Henry Moseley was a bright young scientist working in Ernest Rutherford's laboratory when he proposed that the proton is responsible for the atomic number. He also suggested and that the missing mass of the atom is due to a neutral particle in the nucleus with a mass equal to that of the proton.

However, he never had the chance to finish his work because he was killed in the Battle of Gallipoli during World War I. As a result of his death and the shock it created many countries passed laws to prevent young scientist from serving in the armed forces as soldiers.

It should be noted that in 1905 Phillip Lenard was awarded a Nobel Prize for his work with cathode rays. J.J. Thomson won a Nobel Prize in 1906 for his work with the electron. Ernest Rutherford was awarded a Nobel Prize in 1908 for his discovery of the atomic nucleus. Robert Millikan won the Nobel Prize in 1923 for his work on the electron and the photoelectric effect. James Chadwick received the Nobel Prize in 1935 for his discovery of the neutron.

Most likely Henry Moseley would have been awarded the Nobel Prize in 1916, but he died before his time and you must be living in order to be nominated. The prize was awarded to no one that year.

ATOMIC STRUCTURE

The discoveries made by these men outlined a basic description of the atomic structure. A structure we can work with to describe atomic mass, mass number, isotopes and ions.

The Atomic Description

The **atom** is mostly space with a small, very dense nucleus containing positively charged protons and neutrally charged neutrons. The masses of the protons and neutrons account for the mass of the atom. The negatively charged electrons occupy energy levels in the atomic space and for the atom to be stable the number of electrons must equal the number of protons.

Isotopes

Dalton's idea that all atoms for a certain element were the same had to be discarded with the discovery of isotopes. **Isotopes** are atoms of the same element that differ in the number of neutrons. Almost all elements exist as two or more isotopes and each isotope has a different atomic mass. Therefore, a weighted average of the isotopes of an atom, referred to as the **relative atomic mass**, is used on the periodic table.

The **mass number** (A) is the sum of protons (Z) and neutrons (N) and is used to distinguish between different isotopes of the same element. The mass number is not a true mass and should not be confused with the atomic mass.

Ions

Atoms of the same element that differ in the number of electrons are called **ions**. If an atom gains electrons it is an **anion** and if it loses electrons it is a **cation**. Since electrons have a negative charge the anion is a negative ion and the cation is a positive ion.

Nuclide Symbols

The nuclide symbol is a method of writing certain information about an element's ions and isotopes. It should include the mass number (A), the atomic number (Z) and the charge.

$$^{35}_{17}\mathrm{Cl}^{-}$$

List the number of protons, neutrons, electrons for the following isotopes.

isotopes	$^{3}He^{2+}$	^{207}Pb	$^{36}Cl^{-}$	$^{11}B^{3+}$
protons				
neutrons				
electrons				

Think It Through

- What are three main questions about the electron?
- Why bother with the electron?
- What is a scientific model?
- Do you know the difference between direct and indirect evidence?
- What is the Solid Sphere model?
- Describe the Law of Definite Composition.
- Describe the Law of Multiple Proportions.
- What is the Plum Pudding model?
- What is the Nuclear model?
- Who were the men involved?
- What are the subatomic particles?
- Can you describe the atom?
- What is the atomic number? Mass number?
- What is an isotope?
- What is and ion? Cation? Anion?
- Can I write and interpret a nuclide symbol?

Vocabulary

ion	neutron	isotope	nucleus	atomic number
cation	electron	cathode	model	mass number
anion	proton	anode		

Ideas

Law of Definite Composition
Law of Multiple Proportions
Gold Foil Experiment
Plum Pudding model
Nuclear model
Oil Drop Experiment
atomic description
nuclide symbols

People

Democritus
John Dalton
George Stoney
James Chadwick
Eugene Goldstein
Julius Plucker
J.J. Thomson
Robert Millikan
Philipp Lenard
Ernest Rutherford
Henry Moseley

Video Toolbox

The Importance of the Electron
The Solid Sphere Model
The Plum Pudding Model
The Nuclear Model

Nucleons and Subatomic Particles
Atoms, Isotopes and Ions

"I am enough of an artist to draw freely upon my imagination.
Imagination is more important than knowledge.

Knowledge is limited.
Imagination encircles the world."
--Albert Einstein