Atomic Structure – from Democritus to quanta

The Greek philosopher Empedocles (~445 B.C.) philosophized the following 'theory' of the structure of matter: "…he speculated that the stuff of the world was made of different 'roots.' The roots were seen as being elemental, in that they were original and had always existed, as well as being 'indivisible' or atomic (*atomon* is the Greek word for 'indivisible')." The 'roots' or elements were fire, earth (solids), air (gases), and water (liquids). Fire was often associated with changes between the latter element forms (changes of state) and was considered one of the elements.

Democritus was a Greek philosopher (~450 B.C.). His idea was that stuff was made up of these "atoms" which were in constant motion, much like the kinetic theory of matter. Democritus is often considered the originator of the first true atomic theory because of the influence of his writings on those that would follow him. Aristotle developed the idea of the four elements in terms of the changes associated with the elements in nature which led those that followed to explore both process and structure as one in the same. The recognition of the study of process and structure as separate is associated with the foundations of modern chemistry.

Early alchemists – 1200-1500's – Provided large amounts of recorded data/observations of many different physical and chemical reactions while attempting to change "base" metals into "precious" metals.

Robert Boyle (1661)Recognized chemical elements as "certain primitive and simple bodies not being made of any other bodies or of one another".

Antoine-Laurent Lavoisier (1785) Known as the "father of modern chemistry", defined a chemical element as something that could not be decomposed by chemical means into simpler substances. Identified about thirty of what we now know to be elements in the modern sense of an element.

John Dalton (1808) – Used previously recorded data/observations to develop the first true **atomic theory**:

1. All matter is made up of indivisible and indestructible atoms
2. Atoms of the same element always have the same properties.
3. Atoms of one element have different properties from atoms of another element
4. Atoms of different elements combine chemically in simple whole number ratios to form compounds
5. Atoms cannot be subdivided, created, or destroyed when they are combined, separated, or rearranged in chemical reactions

Parts of Dalton's theory have been modified, but the basic principles underlying it have not been disproved – we just keep finding smaller pieces.

J.J. Thomson (1898) – piece number one – The electron. During the 1800's many devices were developed to study the behavior of electricity. Two of these devices assisted in the discovery of the electron as well as identifying its electrical charge, Crooke's Tube and the cathode ray tube (CRT). Both are gas chambers nearly completely evacuated of air. Crooke's tube contained a paddle wheel which moved when an electric current was applied to the ends of the tube. This movement of the wheel indicated that electricity must be composed of particles, **electrons**. The CRT was a glass tube that had not been completely evacuated, but had some traces of gas which illuminated due to the electric current applied to the ends of the tube. This allowed the beam of electrons to be seen and its behavior observed. This helped define the charge of the electron as negative, relative to the previously assigned positive cathode and negative anode. With this information Thomson developed a model of an atom called the plum pudding model. This model explained the atom as a solid positive sphere sprinkled with negative electrons, the atom was known to be electrically neutral.

Ernest Rutherford (~1910) – Rutherford and his team were studying the effects of radioactivty on various metals. According to the current models of the atom the radioactive particles should pass through thin layers of metal in a nearly straight path. Shockingly some particles were deflected by the thin foils at every angle, even straight back where they came from. "*It was like firing an 18 inch artillery shell at tissue paper and having it bounce back!*" was reportedly Rutherford's response. Based on this new information it was determined that the atom must be composed of a tiny positively charged **nucleus** surrounded by the electrons, most of the volume of the atom had to be empty space.

Henry Moseley (~1913) – Piece number two – The proton. Moseley was studying the effect of X-rays on different elements and noticed that each had a different **Z** number as he called it, this was determined (by James Chadwick in 1920) to be the number of **protons** contained in each element. The Z number, or **atomic number**, is unique to each element. The proton is positively charged an 2000 times as massive as the electron. The protons are located in the tiny nucleus.

Niels Bohr (~1921)– Planetary model – Bohr suggested that the atom's structure was similar to the solar system. The sun was the nucleus and the planets were the electrons, which had specific orbits. Bohr stated that the electrons were in energy levels of specific quantities of energy, or **quanta**. According to Bohr and current theory, the electrons could only reside in specific **energy levels**.

Irene Joliot-Curie, James Chadwick – ~1930's – As measuring methods became more precise it was noted that much of the mass in an atom was unaccounted for by just the protons and electrons, so there must have been something else in there. The **neutron** was discovered through the study of the effects of radioactivity on beryllium. The neutron is neutral in charge and has a mass similar to the proton.

The structure of the atom was fairly well set at this time – A nucleus containing protons (+) and neutrons (neutral) of nearly equal mass "orbited" by electrons (-) in specific energy levels and a mass 1/2000 of the proton. The current model of the atom differs due to the discovery of particles composing protons and neutrons, such as quarks, and a less specific model of the electron behavior known as the **electron cloud model**. The current atomic model and theory is described and studied through **quantum theory**, a mathematical description/explanation of what is believed to be the true nature of the atom.

Based on information we have about the currently known elements we can identify the numbers of each sub atomic particle as well as the mass of the atom (almost entirely from protons and neutrons). Refer to Atomic Structure worksheet #1.
The mass of an atom is usually given in terms of the **atomic mass unit (amu)**. This is defined as 1/12th the mass of the carbon atom, which has a mass of 12 amu. The amu is simply an easier unit to use for quick calculations instead of masses in terms of 10^{-26} grams. Another helpful unit of measure in chemistry is the **mole**. It turns out that the *gram mass* of one mole of a substance is equal in number to the *amu mass* of one particle of that substance. For example, an atom of oxygen has an atomic mass of 16 amu, while a mole of oxygen has a mass of 16 grams. A mole is similar to a pair (2), a dozen (12), or a trio (3) in that it simply represents a number, a large number: **6.02×10^{23}**

In addition to the typical atomic structure of an element, some atoms of an element may have a different number of neutrons. These are called **isotopes** of an element. The **average atomic mass** of an element is a weighted average of all the naturally occurring isotopes of that element. Elements may also change by gaining or losing electrons, this results in what are known as **ions**.

Element Symbols for which you are expected to know the names:

Na	Ni	S
Cs	Mo	Fe
Fr	Ge	At
H	W	Br
K	C	U
Li	Si	I
Rb	Sn	F
Zn	Pb	Cl
Ti	Pt	Ac
Ra	Zr	Rn
Mg	Bi	He
Ca	N	Ar
Sr	P	Ne
Be	As	Xe
Hg	Pu	Kr
Ba	Sb	Cd
Ga	Mn	Cu
In	Po	Sc
Cr	La	Co
V	O	Au
B	Y	Tc
Al	Te	Es
Tl	Se	Md

Introduction- Nuclear reactions involve changes in the nucleus of atoms. Three types of nuclear reactions are: 1. nuclear decay, 2. nuclear fission, and 3. nuclear fusion.

Nuclear Forces-

Inside the nucleus, the protons are repelling each other. Every pair of protons has a repulsive force between them. The force is large because the distances within the nucleus are very small. Protons have an electrical force pushing them apart, but a larger nuclear force holding them together. Nuclear force is strong at short range. Neutrons are also attracted to each other and to protons with the nuclear force.

Nuclear force:

- very, very very strong @ at short distance
- acts only between nucleon
- always attractive
- is very short range- (if nucleons are more than 10^{-14}m apart, nuclear force is zero).

Inside the Nucleus- Scientists refer to protons and neutrons as **nucleons.** Both reside in the nucleus and are almost identical in mass. The mass number tells you the number of nucleons. The mass number is the average atomic mass rounded to a whole number. The average atomic mass of any element exists because not all atoms of a given element have the same number of neutrons in the nucleus.
Only the number of protons is the same in all atoms of a given element. Atoms of the same element with different number of neutrons in the the nucleus are known as **isotopes.** Isotope implies "same number of protons." Isotopes are identified by their mass number, the sum of the number of neutrons plus protons. Element notation is a symbolic way to distinguish the isotopes of a given element. Chlorine, atomic number 17 has two naturally occurring isotopes. Written in element notation they are $^{35}_{17}\mathbf{Cl}$ and $^{37}_{17}\mathbf{Cl}$ Chlorine has a third isotope $^{36}_{17}\mathbf{Cl}$, but it unstable. Unstable isotopes decay into other elements.

Unstable Atoms = Nuclear Decay- Three ways unstable nuclei decay are: alpha, beta, and gamma emission.

In alpha emission, the nucleus "spits out" a particle that has 2 neutrons and 2 protons. This is identical to the nucleus of helium Its chemical symbol is $^{4}_{2}\mathbf{He}$ and it is referred to as an **alpha particle**. Alpha particles are what Rutherford used in the Gold Foil Experiment. Look at the example of the alpha decay of uranium-238

Alpha Decay

$$^{238}_{92}\mathbf{U} \rightarrow {}^{4}_{2}\mathbf{He} + {}^{234}_{90}\mathbf{Th}$$

alpha particle

In beta emission, the nucleus "spits out" a high-speed electron. The electron was not residing in the nucleus. A neutron in the nucleus decayed into a proton and an electron and the electron was ejected. The symbol for this high-speed electron is ${}^{0}_{-1}\mathbf{e}$ and it is referred to as a **beta particle**. Look at the example of the beta decay of Carbon-14.

Beta Decay

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathbf{e}$$

beta particle

In gamma emission, the nucleus "spits out" a packet of electromagnetic radiation. This does not change the atomic number or the atomic mass of the element. The symbol for gamma emission is γ and it is referred to as a gamma particle or gamma ray.

Alpha, beta, and gamma emissions can be a health risk or a medical therapy. Radiation can harm both cancer cells and healthy cells. A thin sheet of material can usually block alpha particles. A thicker shield is required to block beta particles. An even greater shield is required to block gamma rays.

Nuclear Fission & Fusion-

Stability of an atom varies with the elements. Light elements become more stable as the atomic mass (nucleons) increases. Iron is the most stable element (atomic number 26) with an mass number of 56 amu. Elements with larger atomic masses become less stable. **Nuclear fission** involves the splitting of a heavy nucleus into two lighter nuclei, releasing energy. This is the process used to produce nuclear energy. It is used to power nuclear submarines and to produce electrical energy in power plants all around the world.

In general, elements with nuclear mass much less than 56amu can combine to gain mass, become more stable, and give off energy. This is called **fusion**. Fusion is the process of small nuclei combining to increase their mass. The best example of fusion is what occurs in the Sun and other stars. Theoretically, the fusion process is ideal for supplying safe energy because it releases very large amounts of energy without leaving much dangerous radioactive residue. At the present time, it is very difficult to accomplish this on an industrial level. In the future, scientists hope to figure out how to harness the energy of nuclear fusion, because it would be an excellent energy source for society. See PowerPoint

Half-Life- The disposal of nuclear waste presents many problems specifically the half-life of the by-products of nuclear-power generation. Fission creates many radioactive isotopes each emitting its own hazardous radiation at its own rate. This is known as half-life. **Half-life** is the amount of time required for half of the nuclei in a sample of radioactive atoms to undergo nuclear decay.