Nuclear power for mechanical engineers
by Ralph W Arboe

A THESIS Submitted to the Graduate Faculty In partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering at Montana State College
Montana State University

Abstract:
This thesis was written to be used as a text for M E. 508, Atomic Power Engineering and consists of declassified material released by the Atomic Energy Commission, as well as this student's original ideas end presentation. The presentation is on a level for a graduate student. All of the complicated mathematics and physics have been eliminated and only a straight-forward engineering approach presented.

The introduction starts with the basic concept of the atom and its structure. Also in the introduction are a table of definitions and conversion tables for converting energy, mass and charge units. The brief review in the introduction is then used as a background for the remainder of the thesis.

The discussion then turns to a brief history of the findings of radioactivity, isotopes, isomers, artificial radioactivity, nuclear reactions, neutrons and positrons. Nuclear energy is explained and the type of reactions needed to produce energy by means of nuclear reaction and fission.

Separation of isotopes and the detection of radiation must be understood before a useful reactor may be designed. The types of reactors are discussed showing the advantages of one type over the other.

In conclusion all of the aforementioned material is compiled to use nuclear power for industrial uses. Nuclear power is put to use in aircraft, power stations, locomotives, industrial processes and heating. Calculations show the amount of nuclear fuel required in comparison to coal and oil, as well as a cost comparison.

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Approved:

Head, Major Department

Chairman, Examining Committee

Dean, Graduate Division

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INTRODUCTION

ANOTHER LOOK INTO THE ATOM

Before the turn of the century (1880-90), the Physicists were content to believe that nothing new could be found and that they had explained every phenomenon. The future technical outlook appeared as if all experimental and research work would have to be along the lines of already existing theories. This belief did not last long, because a series of discoveries starting with Wilhelm Roentgen's discovery of X-rays in 1895, Henri Becquerel's discovery of natural radioactivity in 1896, also the work of the Curie's, J.J. Thomson, Max Planck, Rutherford and Soddy, Einstein, Bohr, Aston, Compton, Chadwick, the Joliot's, Fermi and Oppenheimer, with the final result being the Atomic Bomb. (The above mentioned scientists and their work will be discussed in the following pages.)

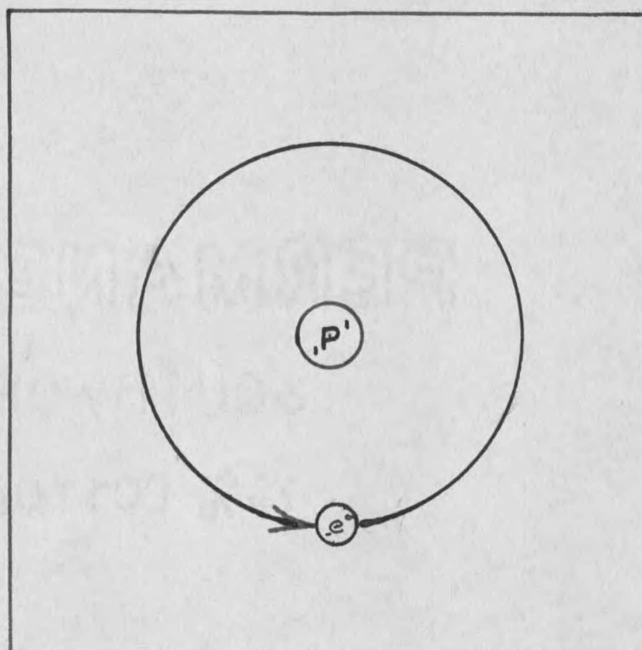

Figure 1 The Hydrogen Atom

Before continuing with our discussion let us examine the present concept of the atom. According to the present concept every atom consists of a small heavy nucleus approximately 10^{-12} cm in diameter surrounded by a large empty region 10^{-8} cm in diameter[1] in which electrons move somewhat like the planets about the sun. The nucleus having a positive charge (the amount depending on the individual atom) which is counterbalanced by an equivalent negative charge of the electrons (or electron). The mass of one electron is 2.01×10^{-30} lbs. or 9.1066×10^{-28} gms. Because of these awkward units the physicists have used another unit for the mass of these small particles, being the atomic mass unit (1 amu = 1.66×10^{-24} gms) which is based on the most abundant isotope[2] of oxygen having a mass of 16 atomic mass units.[3]

In examination of the smallest and simplest of the atoms, the hydrogen atom, we find that its simplicity is drawn from the fact that it has only one electron. As a result it needs only one positive charge in its nucleus (See Figure 1). The hydrogen atom has an atomic number (Z) of one, the next atom in sequence is the helium atom with an atomic number of two.

The helium atom has two electrons and two positively charged particles in its nucleus and therefore its weight should be twice that of the hydrogen atom. Referring to the mass of the hydrogen atom 1.00813 atomic mass units and the helium atom 4.003 atomic mass units we can see

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1 It is interesting to note that the diameter of the electron orbits is 10,000 times the diameter of the nucleus, and that all matter is made of atoms but only a very small volume of the atom is comprised of the nucleus and electrons, the rest of the volume being empty.

2 Isotopes will be discussed later.

3 In chemistry the mass is slightly larger. This is because the unit is established by assigning the value 16.000 not to the predominant $_{8}O^{16}$ isotope, but to oxygen as it occurs in nature. The ratio of the mass of an object on the physical scale to its mass on the chemical scale is 1.00027.

that the mass ratio is approximately four and not two as we assumed. (At the present time the physicists have accurately determined the masses of the atoms and various isotopes). Our assumption was erroneous and there must be something else in the nucleus besides these two positively charged particles (protons). The other particles were found to be neutrons,[4] a particle with no charge and a mass approximately that of the proton.

Therefore, the helium nucleus is made of two protons and two neutrons with two electrons moving in their orbits (Figure 2). The helium atom has an atomic number of two, an atomic mass number of four, and atomic weight of 4.003 amu. For future reference the atomic number, atomic mass number, and atomic weight will be designated by the symbols Z, A and M respectively.

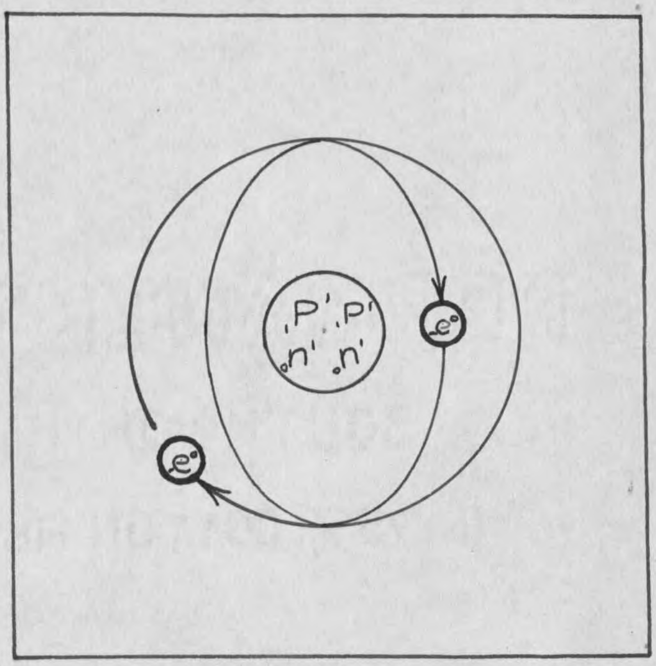

Figure 2 The Helium Atom

The atomic number (Z) is the number of positive charges in the nucleus. It determines the number of electrons in the extra-nuclear structure, and this in turn determines the chemical properties of the atom.

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4 The discovery of the neutron will be discussed in detail later.

Thus all the atoms of a given chemical element have the same atomic number, and conversely all atoms having the same atomic number are atoms of the same element regardless of possible differences in their nuclear structure. The electrons in an atom arrange themselves in successive shells according to well-established laws. Optical spectra arise from disturbances in the outer parts of this electron structure; X-rays arise from the disturbances of the electrons close to the nucleus.

If we go back to a fundamental law of physics, Coulomb's Law of Force between electrically charged particles,

$$F = \frac{q_1 \ q_2}{kr^2} \qquad (1)$$

where F is the force in dynes, q_1 and q_2 charge on particles 1 and 2 in coulombs, r distance between particles in cm and k is the dielectric constant. The significance of this law is to calculate the force between charged particles, whether they have the like or opposite charges. As we already know, like charges repel each other and opposite charges attract. The nucleus of the helium atom is comprised of two protons and two neutrons. The charge on a proton is plus 4.805×10^{-10} stat-coulombs. There are two protons both having a positive charge, therefore, from Coulomb's Law, there must be a force of repulsion.

A present anolagy is that there are two types of opposing forces in the nucleus, those of attraction and those of repulsion. The electrostatic force of repulsion, (long range force) is due to the like charges of the protons. This force may be fairly large; it has been calculated that two grams of protons placed at opposite poles of the earth would repel each other with a force of 26 tons. The forces of attraction in the nucleus, called nuclear forces (short range forces) exceed even the electrostatic forces. These forces of attraction exist between protons, between neutrons and between protons and neutrons. These forces are not predominate except at very close range. If we were to graph these two forces against the distance (r) between the charged particles, the long range force would decrease exponentially from a distance of approximately $3x10^{-12}$ cm to where the force approaches zero at a distance of infinity. The short range forces are only in effect up to approximately $3x10^{-12}$ cm. (Figure 3). The height of the curve x is generally referred to as the potential barriet; any positive charged particle moving toward a nucleus must have sufficient energy to overcome this potential barrier to enter the nucleus. But neutrons have no charge and are not effected by this long range electrostatic force, therefore, a neutron moving in the direction of a nucleus will not have to overcome this potential barrier and may move directly within range of the nuclear

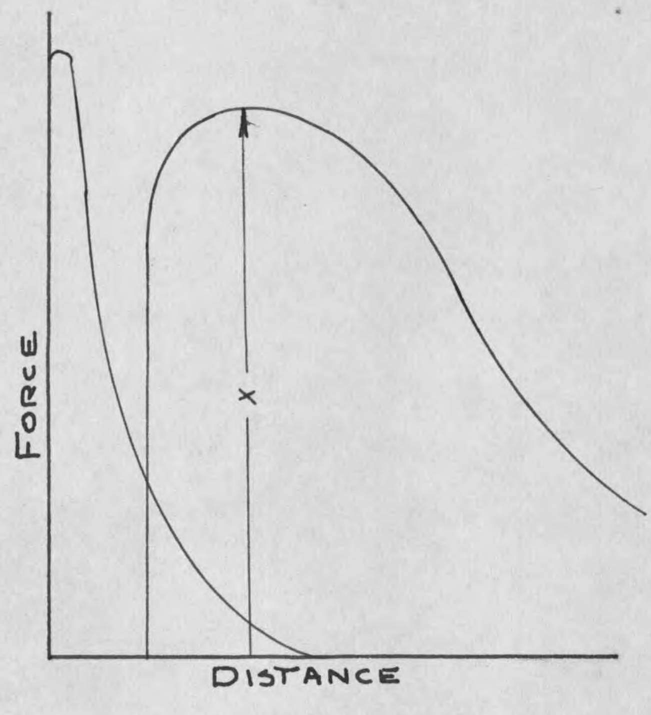

Figure 3 Comparison of Electrostatic Forces to Nuclear Forces as plotted against Distance

forces of attraction (this is the secret to nuclear energy and will be referred to at frequent intervals). However, these short range forces reach a point of saturation depending on the individual nucleus. Two hydrogen atoms attract each other very strongly to form a hydrogen molecule (H_2) and then attract no additional atoms, also two protons and two neutrons tend to unite into the helium nucleus with comparable saturation effects.

An isotope of uranium $_{92}U^{235}$ will have in its nucleus 92 protons and 143 neutrons but let us examine the forces acting on these particles. The uranium atom has an atomic number of 92 and an atomic weight of 238.07. The force on a proton in the center of the nucleus is the nuclear force of attraction for any of its adjacent particles (other protons or neutrons, short range forces). But a proton on the outside surface of the nucleus is in contact with less neutrons and protons, and a proton on the opposite side of the uranium nucleus may be beyond the short range and be in the range for the electrostatic forces of repulsion. Taking this into consideration it can be seen that some of these heavier atoms, although stable, may be disrupted very easily; an example of what may happen is easily shown by taking a drop of water and letting it fall from some high point (the gravitational force acting on the drop will be, $F = mg$). The drop will split into two halves.

So far this discussion has two main purposes, first to give a very brief resume of the atom (for a more detailed discussion see any college physics text) and second to give the reader several new things to think about.