2 ATOMIC STRUCTURE

Nearly 2500 years ago Greek scholars speculated that the substances around us are made of tiny particles called atoms. A limited number of different kinds of atoms in various combinations can construct the whole vast array of nature. John Dalton, a nineteenth century English Chemist, formalized the modern theory of atoms in six basic points:

1. Ordinary matter is composed of particles called atoms.
2. Atoms are far too small to be observed with the naked eye.
3. Different chemical elements are made of atoms with different masses.
4. All atoms of the same chemical element are identical.
5. Atoms combine in simple ratios to form new substances but the atoms themselves remain unchanged.
6. Atoms cannot be divided, created, or destroyed.

With a minor change to point 4 to account for isotopes (see below) the first five points are correct. The twentieth century has demonstrated point 6 to be wrong. Atoms can be split into more fundamental particles: the proton, neutron, and electron.

2.1 Fundamental Particles

2.1.1 Proton

A proton is a very small particle. Its diameter is about one hundred thousandth (1/100,000 = 10^{-5}) of the diameter of a hydrogen atom. The diameter of a hydrogen atom is about one ten-billionths of a meter, 10^{-10}m.

The proton carries a single unit positive charge (+1e) and has a mass of about one mass unit (1u). The mass unit is very small: 1u=1.66 x 10^{-27} kg. The proton mass is 1.0073 u and most of the time we round this off to 1u.

2.1.2 Neutron

A neutron is a neutral (uncharged) particle the same size as the proton. Its mass is 1.0087 u, about 2½ electron masses heavier than the proton. We generally approximate its mass as 1u.

2.1.3 Electron

An electron is the smallest of the three fundamental particles, with a mass of only 0.000 548 u, about 1/1840 of the mass of a nucleon. (Nucleon is a name for either of the two heavier fundamental particles.)

The electron carries a unit negative charge (-1e). The unit charge is so small it takes a flow of 6.24 trillion charges a second to measure a current of one microampere.

2.2 Structure Of Atoms

We shall now see how to assemble these fundamental particles to make atoms.

Danish physicist Niels Bohr received the Nobel Prize in 1922, for his theory about the structure of atoms. The picture that the Bohr model presents is of a small clump of protons and neutrons (the nucleus) surrounded by electrons in orbit. The atom according to this model, is like a very small solar system, with the electric force between the positive nucleus and the negative electrons playing the role of gravity.

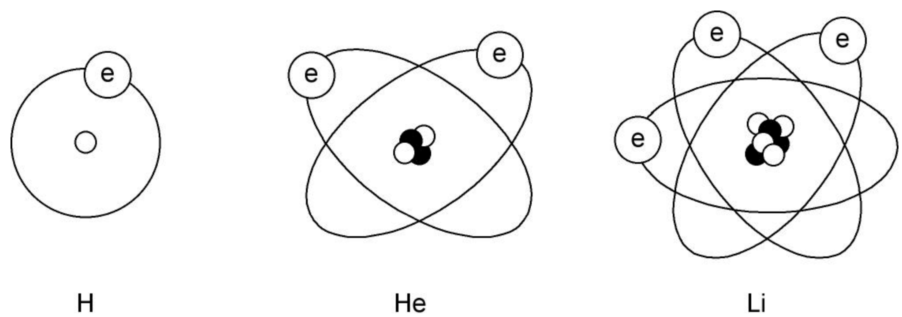

Figure 2.1

Each atom of an element has a characteristic number of protons in its nucleus. A neutral (that is, uncharged) atom has the same number of electrons in orbit as there are protons in the nucleus. Figure 2.1 illustrates the first three elements: hydrogen, helium, and lithium.

There are over 110 chemical elements. Ninety elements exist naturally in the world around us and most of these (81) are made of stable atoms. A few unstable atoms (i.e., radioactive atoms) also occur naturally, and the "man-made" atoms are all unstable.

2.3 Atomic Notation

Each kind of atom can be identified and represented by its chemical symbol, its atomic number (number of protons), and its atomic mass number (equal to the number of nucleons) as follows:

$^{A}_{Z}X$ Where: Z = Atomic Number

X = Chemical Symbol

A = Atomic Mass Number

The symbol $^{A}_{Z}X$ represents a neutral atom of chemical element X.

For example, the three elements of Figure 2.1 are:

Hydrogen $^{1}_{1}H$ (1 proton, 1 electron)

Helium $^{4}_{2}He$ (2 protons, 2 neutrons, 2 electrons)

Lithium $^{7}_{3}Li$ (3 protons, 4 neutrons, 3 electrons)

Since the number of protons uniquely determines the chemical symbol, we often write these in a simpler way:
$^{4}_{2}He$ becomes He-4 or helium-4.

2.4 Isotopes

The lithium atom in Figure 2.1 has 3 protons and 4 neutrons in its nucleus. Only 92.5% of naturally occurring lithium atoms are like this. The other 7.5% of lithium atoms have three protons and three neutrons. We call these different kinds of lithium atoms isotopes of lithium. The symbols Li-6 and Li-7 represent them.

Isotopes of an element have the same number of protons in their atoms but varying numbers of neutrons. All isotopes of a given element have similar chemical and physical properties but may show very large variations in nuclear properties (in lighter nuclei the mass varies greatly between isotopes).

Isotopes of the elements hydrogen and uranium are particularly significant in this course. Hydrogen has three isotopes (hydrogen, deuterium, and tritium) shown in Figure 2.2. The first two occur naturally, although deuterium is only 0.015 % abundant (about one atom in every 7000). CANDU reactors use deuterium in the form of heavy water (D_2O) to slow fast neutrons and to carry heat from the fuel. Heavy water production requires an expensive separation process (discussed in another course).

The third isotope, tritium, is produced in CANDU reactors. It is radioactive and can be a serious health hazard.

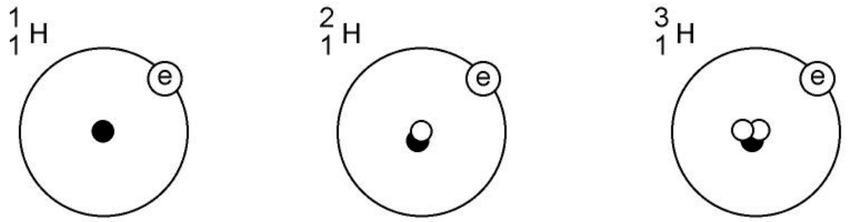

Figure 2.2

Natural uranium used for CANDU fuel has two isotopes, $^{238}_{92}U$ and $^{235}_{92}U$. U-235 is 0.7% abundant and will fission (split, releasing energy) when struck by a low energy (slow speed) neutron. It is said to be fissile. U-235 is the only naturally occurring fissile material. U-238 is 99.3% abundant and is not fissile. Nevertheless, it strongly affects the behaviour of nuclear fuel, as we will see later.

The existence of chemical elements with different atoms could cause confusion. When the numbers of nucleons in the nucleus of an atom are specified (i.e., both Z and A) the word nuclide sometimes replaces the word atom. For example, "The Chart of Nuclides" is a chart setting out the properties of each distinct atomic type (all the isotopes of each element).

2.5 Summary Of Key Ideas

- Atoms are made of protons, neutrons and electrons.
- Protons have a mass of 1 amu and a positive electric charge. Neutrons have a mass of 1 amu and no electrical charge. Electrons have a mass of 1/1840 amu and a negative electrical charge.
- The number of protons and hence the number of electrons in a neutral atom determine the chemical and most of the physical properties of an atom.
- Isotopes are atoms with the same number of protons and different numbers of neutrons in the nucleus.

- Isotopes of an element behave differently in a nuclear reaction.

- ${}_{Z}^{A}X$ notation is the standard for specifying nuclides.

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2.6 Assignment

1. List the mass, charge, and atomic location of each of the fundamental particles.

2. Define an isotope.

3. Describe the atomic structure of ${}^{3}_{1}H$

4. Sketch the atom ${}^{10}_{5}B$.

5. Define or describe each of the following: atom, element, nuclide, nucleon, atomic number, mass number, and mass unit.