Atomic Structure

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Basic Ideas

1. Atoms are composed of a small, dense, positively charged nucleus surrounded by negatively charged atoms
2. All electrons are identical in mass and charge
3. Protons and neutrons reside in the nucleus and are almost 2,000 times more massive than electrons. Neutrons are electrically neutral and have a "dab" more mass than protons.
4. Normal atoms have the same number of protons as electrons. If these are not the same we have an *ion.* Positive ions have more protons than electrons; negative ions have more electrons than protons.

5. Electrons close to the nucleus are held tightly; electrons far away from the nucleus are held more loosely.

Brief History

1752 – Ben Franklin – lightning is a flow of electrical energy

1887 – J. J. Thompson – discovered charge to mass ratio of electron in cathode ray tube

1909 – Rutherford – his gold foil experiment proved that nucleus is small, dense and positively charged

1911 – Millikan – his oil drop experiment gave charge on a single electron

1911 – Bohr – Planetary model of the atom based on quantum theory of light

1930 – Chadwick – discovered neutron

Quantum theory of light

So far we have studied light (electromagnetic radiation) as a wave. In the late 1800’s several discoveries pointed to the fact that not all of light’s properties can be explained using a wave theory.

Photoelectric effect – When light hits a surface it is possible for electrons to be emitted. This is how solar cells work. It was found that only certain frequencies of light would accomplish this and that the KE of the emitted electrons was proportional to the frequency of the light. As a result of these experiments, Einstein used the

ideas of Max Planck to prove that light has particle properties as well as wave properties. This is called the quantum theory of light.

In this theory light is composed of a stream of particles called photons. The energy of each photon is proportional to the frequency of the light.

$$E = hn$$

h = Planck's constant (6.63 x 10^{-34} J/Hz), E is the energy of the photon in Joules and n **is the frequency in Hz.**

The Bohr Model of the Atom

- **In the Bohr model electrons travel in circular orbits called energy levels around the nucleus.**
- **The potential energy of the electron is negative due to its attraction for the nucleus and gets more positive as the electron gets farther away from the nucleus.**
- **These orbits are restricted (quantized) and electrons can only go from one energy level to another energy level. Each electron has a "home" or ground state.**
- **To go to another orbit it must either give off energy or absorb energy of just the right amount to make the transfer. The transfer of energy is accomplished by absorbing or emitting photons of light.**

The Bohr model works well for explaining the light given off and absorbed by the element hydrogen but does work well for any other substance. We need a better model.

Quantum Mechanics

We have just seen that light has both wave and particle characteristics. Could matter particles have wave characteristics? Yes, and this is the basic idea behind quantum mechanics.

1925 - DeBroglie wavelength equation

wavelength = h/momentum

Application – electron microscope

<u>Electron waves and the electron cloud</u>

Electrons occupy only certain orbits because of the wave nature of electrons. Electron orbits can only occur when the electron wave closes in on itself in phase – and produces a standing wave.

The electron path itself is difficult to visualize. *Heisenberg* determined in the 1920's that it is impossible to determine both the position and velocity of an electron exactly at the same instant. This is called the uncertainty principle. In the late 1920's *Schrodinger* used the ideas of Bohr, deBroglie, and Heisenberg to formulate a wave equation for the electron's path around the nucleus.

This equation gives us the idea of the probability of finding an electron in space. High probability areas are called the shape of the electron cloud. Understanding electrons and how they are lost and gained by atoms to form bonds and new substances leads to an understanding of chemistry. Before we go further let's look at the nucleus.

The Nucleus

The nucleus is of course composed of protons and neutrons (called nucleons) and the nuclear strong force keeps these particles together. This force is only effective at very small distances.

Protons and neutrons are composed of still smaller particles called quarks. Electrons are not composed of quarks and cannot be subdivided.

Isotopes

All atoms of an individual element have the same number of protons. This number is called the *atomic number*.

Not all atoms of each element have the same number of neutrons. The sum of the number of protons and neutrons is called the *mass number*. The

different forms of an element, all of which have the same atomic number but different mass numbers, are called the element's *isotopes*.

The notation $^{y}_{x}Z$ is used to symbolize a certain type of atom or isotope. X represents the atomic number, y the mass number and Z the symbol for the element. Symbols for elements may have one or two letters; the first letter is a capital, the second is lowercase. Another way to identify the isotope is to write the name of the element followed by the mass number (chlorine 35).

Question – Write the symbol notation for carbon 14 and uranium 235. How many protons and neutrons are in the nucleus?

Some nuclei are unstable and can be radioactive.

Radioactivity

Radioactivity is the spontaneous, uncontrollable decay of a nucleus by the emission of high energy electromagnetic radiation and/or particles.

- Alpha particle – 2 protons and 2 neutrons $^{4}_{2}He$
- Beta particle – 1 electron $^{0}_{-1}e$
- Gamma ray – high energy electromagnetic radiation g

Gamma rays are very highly penetrating, beta much less so and alpha particles can be stopped by a sheet of paper.

Radioactive atoms are all around us. Most of the radiation that we receive is due to the natural radioactivity from outer space and earth minerals (56%). Another large chunk comes from medical and dental x-rays (42%). A very small amount comes from fallout from nuclear weapons tests and nuclear power plant operation.

When radiation (including x-rays) encounters a cell, it can break apart or ionize the molecules. This can lead to changes in the DNA and mutations of the cell. These mutations can lead to cancer.

Nuclear Transmutation

When radioactive nuclei give off alpha or beta particles they change into different elements. This is called transmutation. We can use our symbol notation to show this nuclear change. In these equations the mass numbers on the left and right sides must equal and the atomic numbers (and charge of electrons) must equal.

Write the nuclear equation for the nuclear change that occurs when uranium 238 gives off an alpha particle.

Write the nuclear equation for the nuclear change that occurs when thorium 234 gives off a beta particle.

Half life and Radioactive Decay

The time that it takes for half of a radioactive material to decay is called its half-life. These half-lives can be less than a microsecond or as long as billions of years. A short half-life means more radioactive decays measured per second.

If the substance produced is radioactive it can also decay and the process can continue until a stable isotope is reached. For example uranium 238 decays through many steps to lead 206.

The graph of amount of substance versus time is not a straight line for a radioactive substance but is an exponential curve.

Other applications

Artificial transmutation is achieved by bombarding nuclei with other nuclei in hopes that a new element will be formed.

Isotopes are used to date older objects by comparing the radioactivity (carbon 14 dating) or the amount of stable isotopes that must have come from radioactive elements (uranium dating).

There are many medical uses from tracing the path of substances in the body to using the destructive power of radioactive isotopes to kill cancerous tissue.

Fission

Some nuclei can be made to split into large pieces instead of giving off radioactive particles. This is the <u>fission</u> process.

Write the fission reaction when a neutron hits a uranium 235 nucleus and gives products of a krypton 91 nucleus and a barium 142 nucleus.

How many neutrons must also be given off to balance the equation?

Huge amounts of energy can be given off in this process as the mass of the product particles is less than the mass of the original reactant atom. This extra mass is released as heat energy of the particles. In other words a high mass per nucleon particle become lower mass per nucleon particles.

The extra neutrons produced can split other atoms in such a way as to produce a <u>chain reaction</u>. The size of the material that is necessary to sustain a chain reaction is called the <u>critical mass</u>. Not all atoms can be split or even all isotopes of an element. For example uranium 235 splits but not uranium 238.

There is very little uranium 235 in nature (only 0.7%) so the natural uranium must be enriched in uranium 235 in order to produce either bomb material or nuclear power plant material.

<u>Fission reactors</u>

Fission reactors contain three components: nuclear fuel (uranium 235 or plutonium 239), control rods to absorb excess neutrons and keep the reaction from producing an explosion (cadmium or boron) and a liquid (usually water) to transfer the heat created by the fission to a turbine.

The main disadvantage of fission reactors is the production of radioactive waste with long half-lives.

Fusion

In the fusion process small particles are brought together to form more stable particles (less mass per nucleon). Once again the mass of the products is less than the mass of the reactants and heat energy is released.

This is how the stars (including our sun) produces energy. Obviously as the process continues the mass decreases of the star.

Fusion requires very high temperatures (millions of degrees). Matter at this temperature is in the plasma phase (a sea of + and – ions).

At these temperatures regular containers melt so a magnetic field is used to contain the plasma. We have not developed the technology to contain the plasma for an extended length of time to develop a commercial fusion reactor.

The advantages of this process would be readily available starting materials (hydrogen from water) and very little hazardous waste.