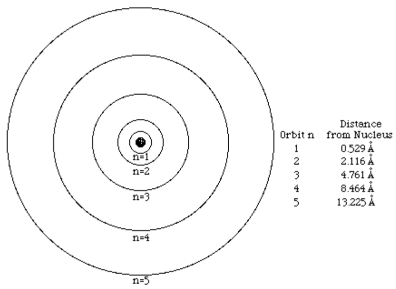
<u>Chemistry Notes:</u> Atomic Theory

2.1.1: Positions of Subatomic Particles

Protons and neutrons are found in the nucleus of an atom, and electrons are found in the electron cloud (a general area in which there is a 90 percent probability of finding an electron at any given point). According to Danish physicist Niels Bohr, electrons are found in an orientation within the orbitals or valences around the nucleus that is unique for all elements. The Bohr model of the atom is shown below:




2.1.2: Relative Masses and Charges of Subatomic Particles

| Particle | Relative Mass | Charge |
|---|---|---|
| Proton | 1 | + |
| Neutron | 1 | 0 |
| Electron | $5 \times 10^{-4}$ | - |

2.1.3: Mass Number (A), Atomic Number (Z), Isotopes

The Mass Number (A) is equal to the sum of the number of protons and neutrons in the nucleus of the atom (Note that this is different than the atomic mass, which is the weighted average of all naturally occurring isotopes of an element).

The Atomic Number (Z) is equal to the number of protons in the nucleus of an atom and is unique to all elements whether they are ionized or not.

Isotopes of an element are atoms with the same atomic number (Z) but different mass number (A) due to a disparate number of neutrons in the nucleus. An example of isotopic notation is shown below:

$$Where\ {}^{A}_{Z}X,\ {}^{35}_{17}Cl\ \ and\ {}^{37}_{17}Cl\ \ are\ isotopes$$

2.1.4: Deduce Isotopic Notation Given A and Z

If we are given element X, with atomic number Z, and mass number A, the isotopic notation can be presented in the following orientations:

$${}^{A}_{Z}X,'\ name\ of\ element' - A, X - A$$

2.1.5: Calculate Numbers of Subatomic Particles Given Mass, Atomic Number, and Charge

Given the following notation:

$$^{37}_{17}Cl^{-}$$

It is possible to deduce that the number of protons (Z) is 17, the number of neutrons is (A – Z) 20, and the number of electrons is 17 + 1 (due to 1- charge, which indicates an ion that gained an electron) = 18.

If the above was not an ion, adding one electron would not be required and the number of electrons would remain equal to the number of protons because atoms have a net charge of 0.

2.1.6: Compare the Properties of Isotopes of an Element

The chemical properties between atoms and isotopes do not change because the number of electrons as well as the electron configuration of the particles does not change. This means that an isotope of an element will form the same compounds as another isotope of the same element.

The physical properties of isotopes are different due to the disparate number of neutrons that yield different mass numbers.

- Isotopes with larger mass numbers have higher boiling points and melting points.

-Isotopes with larger mass numbers have lower freezing points.

- Isotopes with larger mass numbers have a higher density (m/v)

- Isotopes with larger mass numbers are less susceptible to deflection in a mass spectrometer

- Certain Isotopes of an element may be radioactive or 'unstable', while some may be stable

- In gaseous forms, the rate of diffusion of elements with larger masses differs because according to Graham's law of effusion, the rate of effusion of a gas is inversely proportional to the square of the molecular mass of the gas. Therefore the higher the molecular mass or mass number, the slower the gas diffuses.

2.1.7: Discuss the Uses of Radioisotopes

Carbon-14 Dating: Carbon-14 has 8 neutrons and 6 protons, and it reduces the neutron-proton ratio when a neutron changes into a proton and ejects a beta particle from the atom according to the transmutation below:

$$^{14}_{6}C \rightarrow ^{14}_{7}N + {}^{0}_{-1}\beta$$

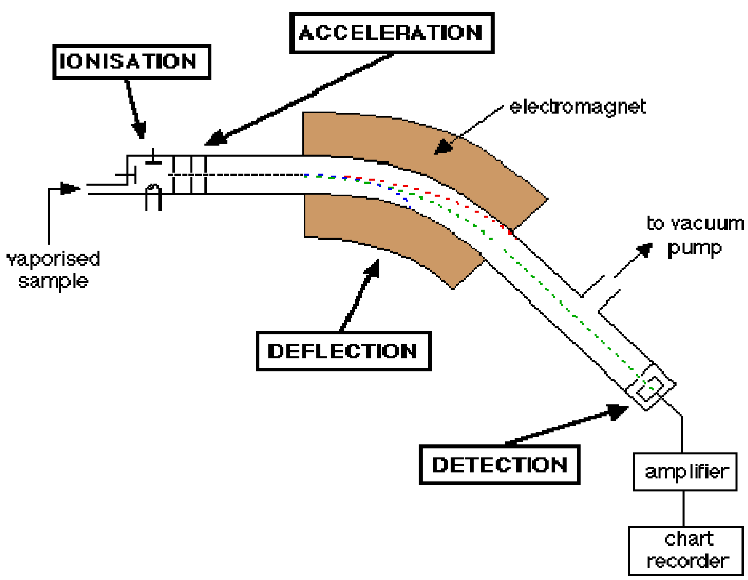
The relative abundance of carbon-14 in organisms is constantly replenished by carbon dioxide in the atmosphere. When organism die, the C-14 levels decays and falls by half every 5730 years, making the C-14 a useful agent for dating structures and organisms.

Cobalt-60 Used in Radiotherapy: Co-60 is used in radiotherapy, or the treatment of cancer with ionizing radiation. Co-60 releases penetrating gamma radiation when its protons and neutrons change their relative positions. This radiotherapy can be used to treat localized solid tumors by knocking of the electrons of cancerous cells and making it impossible for the cancerous cells to grow.

Iodine-131 as a Medical Tracer: Iodine emits both gamma and beta rays and can be used in the form of a compound with sodium iodide to investigate the activity of thyroid glands and diagnose and treat thyroid cancer. It has a short half-life of 8 days and can thus be eliminated quickly from the body.

Iodine-125 Used to Treat Prostate Cancer: Pellets of this isotope can be implanted in to the prostate gland. Due to its 80 day half-life, the isotope can release low levels of beta radiation for an extended period of time.

2.2.1: Describe the operation of a Mass Spectrometer




A mass spectrometer can be used to determine the masses of different isotopes and their relative abundance.

Vaporization – A gaseous sample is injected into the mass spectrometer so that individual atoms can be analyzed.

Ionization – The atoms of the sample are bombarded with high energy electrons, effectively ionizing atoms of the sample producing positively charged ions by the equation below:

$$X_{(g)} + e^- \rightarrow X^+{}_{(g)} + 2e^-$$

Acceleration – the positive ions are attracted by negatively charged plates. They are accelerated by the electric field and pass through a hole in the plate.

Deflection – the accelerated positive ions are deflected by the negatively charged plates that are placed at right angles to their path. The amount of deflection is dependent on three factors:

-Ions with smaller masses are deflected more

-Ions with higher charges are deflected more as they react to the negative charge more

-The stronger the magnetic field, the more deflection

Detection – Positive ions of a particular mass/charge ratio (M/Z) are detected and a signal that marks the number of ions with that ratio that are detected is sent to the recorder.

2.2.2/2.2.3: Describe How a Mass Spectrometer Can Measure Relative Atomic Mass Using the C-12 scale

The relative atomic masses of all atoms recorded by the mass spectrometer are determined in a.m.u's which are equal to $1/12^{th}$ of the C-12 isotope. The mass spectrometer records the percent abundance of each isotope of a given element with a specific mass/charge ratio on a Cartesian plane. This is known as the mass spectrum. In order to determine the relative atomic mass of a sample recorded by the mass spectrometer, you simply need to multiply the mass/charge ratio by the corresponding percent abundance of each isotope, and divide by 100.

In order to find the percent abundance given two isotopes and the atomic mass of an element, you need to set the percent abundance of an isotope in a sample of 100 atoms equal to x. Therefore the other is equal to 100-x. Then multiply the mass number of each isotope by the abundance (100-x and x), and set the final expression equal to the given atomic mass.

2.3.1: Describe the Electromagnetic Spectrum

The electromagnetic spectrum is a smooth gradient of all electromagnetic radiation at different levels of energy. All electromagnetic radiation travels at the speed (c), but can be distinguished by their different wavelengths and frequencies. In the visible spectrum, the color of light is dependent on the wavelength.

The precise relationship between the speed of the wave, the frequency, and the wave length is expressed as:

$$c = f\lambda$$

The **frequency** of the wave is the number of waves that pass through any given point on the wave in one second.

The **wavelength** is the distance between two crests on the wave (a crest is the highest point on the wave, a trough is the lowest point on the wave).

2.3.2: Distinguish Between the Continuous Spectrum and the Line Spectrum

White light is a mixture of light waves of differing wave lengths and colors. When white light passes through a prism it produces the **continuous spectrum** at which point all visible colors merge smoothly together.

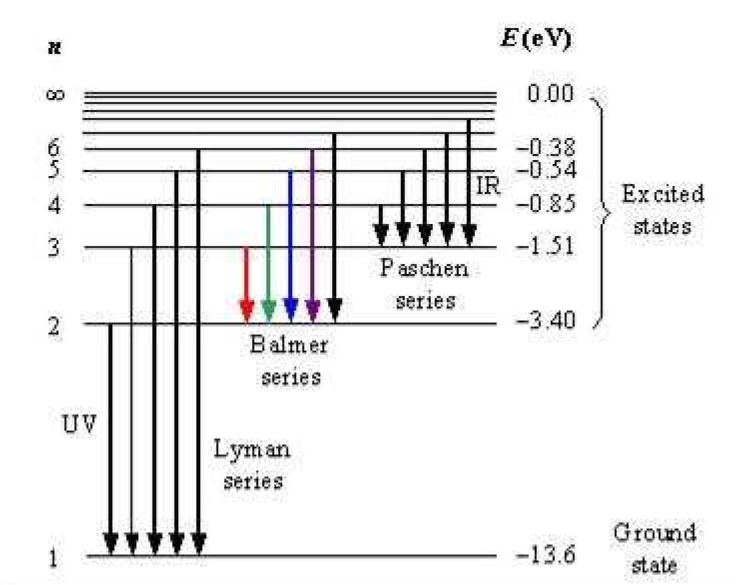
When white light is passed through hydrogen gas, an **absorption spectrum** is produced. This is the spectrum of light that is absorbed by the hydrogen atoms when their electrons jump to higher energy levels. The **line spectrum** is the same thing as the absorption spectrum with some colors missing. The emission spectrum is the spectrum of all colors that are missing from the absorption spectrum. Because each element has a different electron configuration, the emission spectrum can be used as a barcode to determine elements.

2.3.3: Explain How Lines in Hydrogen Emission Spectra Correspond To Hydrogen Electron Configuration

The jump of an electron from higher energy levels to lower energy levels corresponds to the energy released in the form of photons. Because the electrons of certain atoms can only occupy certain orbits, the electromagnetic radiation released by different atoms is different. The energy can only be changed in discrete amounts.

$$\Delta E_{electron} = E_{photon} = hf$$

As electrons move away from the nucleus they absorb energy, as they move towards the nucleus they release energy. The type of radiation released by electrons that fall back to specific energy levels is described in the graph below:




When the hydrogen electron falls back to an energy level of one, the atom emits electromagnetic radiation, when the electron falls back to the second energy level, it emits visible light, and when it falls back to the third energy level, and it emits infrared radiation. Energy levels father away from the nucleus converge as n → ∞. When an electron approaches this it eventually comes to a point where it leaves the atoms and the atom becomes ionized. This explains the convergence of the lines in the emission spectrum of hydrogen.

2.3.4: Deduce Electron Arrangement's for Elements Up to Z = 20

| Element (Z) | Configuration |
|---|---|
| Hydrogen (1) | 1 ($1s^1$) |
| Helium (2) | 2 ($1s^2$) |
| Lithium (3) | 2.1 ($1s^2 2s^1$) or ([He]$2s^1$) |
| Beryllium (4) | 2.2 ($1s^2 2s^2$) or ([He]$2s^2$) |
| Boron (5) | 2.3 ($1s^2 2s^2 2p^1$) or ([He]$2s^2 2p^1$) |
| Carbon (6) | 2.4 ($1s^2 2s^2 2p^2$) or ([He]$2s^2 2p^2$) |
| Nitrogen (7) | 2.5 ($1s^2 2s^2 2p^3$) |
| Oxygen (8) | 2.6 ($1s^2 2s^2 2p^4$) |
| Fluorine (9) | 2.7 ($1s^2 2s^2 2p^5$) |
| Neon (10) | 2.8 ($1s^2 2s^2 2p^6$) |
| Sodium (11) | 2.8.1 ($1s^2 2s^2 2p^6 3s^1$) or ([Ne]$3s^1$) |
| Magnesium (12) | 2.8.2 ($1s^2 2s^2 2p^6 3s^2$) or ([Ne]$3s^2$) |
| Aluminum (13) | 2.8.3 ($1s^2 2s^2 2p^6 3s^2 3p^1$) or ([Ne] $3s^2 3p^1$) |
| Silicon (14) | 2.8.4 ($1s^2 2s^2 2p^6 3s^2 3p^2$) |
| Phosphorus (15) | 2.8.5 ($1s^2 2s^2 2p^6 3s^2 3p^3$) |
| Sulfur (16) | 2.8.6 ($1s^2 2s^2 2p^6 3s^2 3p^4$) |
| Chlorine (17) | 2.8.7 ($1s^2 2s^2 2p^6 3s^2 3p^5$) |
| Argon (18) | 2.8.8 ($1s^2 2s^2 2p^6 3s^2 3p^6$) |
| Potassium (19) | 2.8.8.1 ([Ar]$4s^1$) |
| Calcium (20) | 2.8.8.2 ([Ar]$4s^2$) |

The electron configurations of ions will have the number of more electrons denoted by the charge if it is negative, and the number of less electrons denoted by the charge if it is positive.