An Overview Of Nuclear Chemistry

AP Chemistry Review

A non-electrical, non-gravitational force called the nuclear force holds a nucleus together. Some nuclei are more stable than others. When a nucleus is unstable, it can attempt to increase its stability by altering its number of neutrons and protons. This is the process of radioactive decay.

TYPES OF NUCLEAR DECAY:

Alpha Emission: ${}^{4}_{2}\alpha$ In alpha decay, the nucleus emits a particle that has the same constitution as a helium nucleus, with 2 protons and 2 neutrons.

$${}^{4}_{2}\alpha = {}^{4}_{2}He$$

When a nucleus undergoes alpha decay:
- Subtract 4 from the mass #.
- Subtract 2 from the atomic #.

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

(remember, Thorium is identified by its atomic #, 90)

Beta Emission: ${}^{0}_{-1}\beta$ A beta particle is identical to an electron. In beta decay, the nucleus changes a neutron into a proton and an electron and emits the electron.

$${}^{1}_{o}n \rightarrow {}^{0}_{-1}\beta + {}^{1}_{1}p$$

When a nucleus undergoes beta decay:
- The mass # remains the same.
- Add 1 to the atomic #.

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

Positron Emission: ${}^{0}_{+1}\beta$ A positron is like an electron with a positive charge. In positron emission, the nucleus changes a proton into a neutron and a positron, and emits the positron.

$${}^{1}_{1}p \rightarrow {}^{0}_{+1}\beta + {}^{1}_{0}n$$

When a nucleus undergoes positron emission:
- The mass number remains the same.
- Subtract one from the atomic number.

$${}^{8}_{5}B \rightarrow {}^{0}_{+1}\beta + {}^{8}_{4}Be$$

Electron Capture: ${}^{0}_{-1}e'$ In electron capture, the nucleus captures a low energy electron and combines it with a proton to form a neutron.

$${}^{0}_{-1}e' + {}^{1}_{1}p \rightarrow {}^{1}_{0}n$$

When a nucleus undergoes electron capture:
- The mass number remains the same.
- Subtract 1 from the atomic number

$${}^{18}_{9}F + {}^{0}_{-1}e' \rightarrow {}^{18}_{8}O$$

<u>Gamma Rays:</u> $\;{}^{0}_{0}\gamma$

Gamma rays are electromagnetic radiation and have no mass and no charge. Gamma rays usually accompany other forms of nuclear decay.

Nuclear Stability

Nuclei undergo decay to achieve greater stability. You can use the periodic table to predict the kind of decay an isotope will undergo.

- If an isotope's mass number is greater than its atomic weight, the nucleus will try to gain protons and lose neutrons. If its mass number is greater than its atomic weight, you can expect beta decay.
- If an isotope's mass number is less than its atomic weight, the nucleus will try to lose protons and gain neutrons. If its mass number is less than its atomic weight, you can expect positron emission or electron capture.
- Alpha emission is seen mainly in very large nuclei, usually with atomic numbers of 60 or greater.

Half-Life

The half-life of a radioactive substance is the time it takes for half of the substance to decay. Most half-life problems can be solved by using a simple chart. A sample with a mass of 120 grams and a half-life of 3 years will decay as follows. Don't forget that the chart should start with time at zero.

TIME	SAMPLE (content)		TIME	SAMPLE
0	100%		0 years	120 g.
1 half-life	50%		3 years	60 g.
2 half-life	25%		6 years	30 g.
3 half-life	12.5%		9 years	15 g.

Remember, most radioactive decay is first order overall. The half-life equation is $t_{1/2} = \ln 2/k$. The rate of decay is constant (not concentration dependent) and therefore radioactive elements are used in dating approximations with small levels of uncertainty. The fact that you are **not** allowed to use a calculator for Section One of the AP Exam and the formulae for half-lives are **not** listed on a formula sheet, you should be able to use charts like those above and derive half-life equations from the integrated rate laws.

Mass Defect and Binding Energy

When protons and neutrons come together to form a nucleus, the mass of the nucleus is less than the sum of the masses of its constituent protons and neutrons. The difference in mass is called the *mass defect*. The mass lost in this process is released in the form of energy (all mass can be expressed in energy terms, no? Now my head hurts. . .). If we reverse the process this is the same amount of energy, called the *binding energy,* required to decompose the nucleus back into protons and neutrons. The relationship between mass and energy is given by Einstein's famous equation:

$$\mathbf{E = mc^2}$$

E = energy in (J) **m** = mass (kg) **c** = the speed of light, 3×10^8 m/sec

You can see that because c^2 is such a large number, a very small change in mass results in a very large change in energy.