LESSON 7: NUCLEAR CHEMISTRY
UNIT 2: Types of Nuclear Decay

Introduction:

Nuclear decays are reactions that are spontaneous naturally. These types of reactions are the usual source of radioactivity that we get, albeit they usually give off small amounts of it in the public.

Learning Objectives:

After successful completion of this lesson, the students are expected to:

1. Describe the five common types of nuclear decay.
2. Predict the product of a nuclear decay reaction.

Course Materials:

There are five simple types of nuclear decay: alpha decay, beta decay, gamma decay, electron capture, and positron emission. Each of these reactions would be discussed in this part of the text.

Alpha decay is a nuclear reaction in which an alpha particle is ejected from a nucleus of a radioisotope. By doing so, the result would be a ***nuclide with an atomic number decreased by two, and a mass number decreased by four***.

Examples:

$$^{149}_{64}\mathrm{Gd} \rightarrow {}^{145}_{62}\mathrm{Sm} + {}^{4}_{2}\mathrm{He}$$
$$^{232}_{90}\mathrm{Th} \rightarrow {}^{228}_{88}\mathrm{Ra} + {}^{4}_{2}\mathrm{He}$$
$$^{210}_{86}\mathrm{Rn} \rightarrow {}^{206}_{84}\mathrm{Sm} + {}^{4}_{2}\mathrm{He}$$

In general, for an alpha decay:

$$^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{X}' + {}^{4}_{2}\mathrm{He}$$

where X is the element symbol corresponding to the atomic number Z and X' is the element symbol corresponding to the atomic number $\mathrm{Z}-2$.

Sample Problem 1

Predict the resulting nuclide when $^{222}_{88}\mathrm{Ra}$ undergoes alpha decay. Show also the complete nuclear reaction.

- Since we know that an alpha decay would result in a nuclide with $\mathrm{Z}-2$ and $\mathrm{A}-4$, we have:

$$\mathrm{Z}-2 = 88-2 = 86$$
$$\mathrm{A}-4 = 222-4 = 218$$

The element that has $Z = 86$ is Radon, so the resulting nuclide is $^{218}_{86}\mathrm{Rn}$. The complete reaction is

$$^{222}_{88}\mathrm{Ra} \rightarrow {}^{218}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$

In a **beta decay**, a neutron decays into a proton and an electron. The electron is then emitted by the nucleus, and this emitted electron is now called as a **beta particle**, hence the symbol and the name. Additional studies about this reaction (as theorized by Wolfgang Pauli) has shown that another particle, with no charge and a very small mass that it was thought of before as zero mass, is emitted from a beta decay. This particle is called an **antineutrino**. Overall, the reaction would result in *an increase of one in the atomic number, while keeping the mass number intact*. This is due to the neutron converting into a proton, emitting both a beta particle and an antineutrino.

Examples:

$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\beta + \bar{\nu}_e$$
$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta + \bar{\nu}_e$$
$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\beta + \bar{\nu}_e$$

In general, for a beta decay:

$$^{A}_{Z}\mathrm{X} \rightarrow {}_{Z+1}^{A}\mathrm{X}' + {}^{0}_{-1}\beta + \bar{\nu}_e$$

where X is the element symbol corresponding to the atomic number Z and X' is the element symbol corresponding to the atomic number $Z + 1$.

Sample Problem 2

Complete the following nuclear reaction:

$$? \rightarrow {}^{137}_{56}\mathrm{Ba} + {}^{0}_{-1}\beta + \bar{\nu}_e$$

- For a beta decay, we keep A intact while increasing Z by one. However, since the original nuclide is missing, we must do the opposite. So, we need to subtract one from Z.

$$Z - 1 = 56 - 1 = 55$$

The element with $Z = 55$ is Cesium. So, the complete nuclear reaction is

$$^{137}_{55}\mathrm{Cs} \rightarrow {}^{137}_{56}\mathrm{Ba} + {}^{0}_{-1}\beta + \bar{\nu}_e$$

For a **gamma decay**, a high energy photon is released, which we call as a **gamma ray**. This usually happens when a neutron in an excited state releases energy (in the form of the gamma ray) to achieve a ground state. *Gamma decay does not change both the atomic number and the mass number*. They usually accompany other types of decay, most notably beta decays of most nuclei. They can usually be omitted in writing a nuclear reaction.

In an **electron capture**, an electron in the first shell is captured by the nucleus. This in turn would convert one proton in the nucleus into a neutron. This would also release a non-charged, very small particle called a **neutrino**. Overall, this would result in a *decrease of one in the atomic number while keeping the mass number constant*, which is the opposite of a beta decay.

Examples:

$$^{22}_{11}\mathrm{Na} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{22}_{10}\mathrm{Na} + \mathrm{v_e}$$
$$^{67}_{31}\mathrm{Ga} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{67}_{30}\mathrm{Zn} + \mathrm{v_e}$$

In general, for an electron capture:

$$^{A}_{Z}\mathrm{X} + {}^{0}_{-1}\mathrm{e} \rightarrow {}_{Z-1}^{A}\mathrm{X'} + \mathrm{v_e}$$

where X is the element symbol corresponding to the atomic number Z and $\mathrm{X'}$ is the element symbol corresponding to the atomic number $Z-1$.

Sample Problem 3

If $^{18}_{9}\mathrm{F}$ could hypothetically do both electron capture and positron emission, what would be the nuclear reactions?

- For both these reactions, a decrease of 1 in Z would occur while A is constant. Therefore

$$Z - 1 = 9 - 1 = 8$$

The element Oxygen has $Z = 8$. So, writing the reactions:
Electron capture:

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

Positron emission:

$$^{18}_{9}\mathrm{F} \rightarrow {}^{18}_{8}\mathrm{O} + {}^{0}_{1}\beta + \mathrm{v_e}$$

Lastly, a **positron emission** happens when a proton in the nucleus decays into a neutron and a **positron**, which is then emitted out. This also yields a neutrino. Electron capture and positron emission have the same results: a *decrease of one in the atomic number while keeping the mass number constant*, although they have different mechanisms in doing so.

Examples:

$$^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{K} + {}^{0}_{1}\beta + \mathrm{v_e}$$
$$^{83}_{38}\mathrm{Sr} \rightarrow {}^{67}_{37}\mathrm{Rb} + {}^{0}_{1}\beta + \mathrm{v_e}$$

In general, for a positron emission:

$$^{A}_{Z}\mathrm{X} \rightarrow {}_{Z-1}^{A}\mathrm{X'} + {}^{0}_{1}\beta + \mathrm{v_e}$$

where X is the element symbol corresponding to the atomic number Z and $\mathrm{X'}$ is the element symbol corresponding to the atomic number $Z-1$.

Additional Information

The antineutrino and the positron are examples of **antiparticles** in physics. Antiparticles are usually defined as having similar mass and spin compared to their counterparts (antineutrino is the antiparticle of a neutrino, while positron is the antiparticle of an electron), but with opposite charges. Some particles, like a photon, are their own antiparticle.

One particular trait of a particle – antiparticle pair is that when they collide, **annihilation** occurs. Annihilation produces other particles; in the case of an electron – positron annihilation,

$$ {}_{-1}^{0}\mathrm{e} + {}_{1}^{0}\mathrm{e} \rightarrow \gamma + \gamma $$

Activities and Assessments:

Write the nuclear equations for the following:

1. The beta decay of thorium–234
2. The alpha decay of radon–222
3. The positron emission of manganese–51
4. The electron capture of silver–106
5. The decay of bismuth–212 to polonium–212
6. The decay of radium–226 to radon–222
7. The decay of beryllium–7 to lithium–7