Nuclear Chemistry Notes

Natural radioactivity is the spontaneous disintegration of a naturally occurring radio-nuclides to form a more stable nuclide with the emissions of alpha, beta, positron particles and/or gamma rays. Artificial radioactivity is when we bombard a nuclide with a particle and make it radioactive.

There are 5 different kinds of radiation:

The alpha particle (α) which is the helium nuclei. ${}^{4}_{2}He$

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

The beta particle (β) which is a high speed electron. ${}^{0}_{-1}e$

$${}^{228}_{88}Ra \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}e$$

The gamma ray (γ) which is electromagnetic radiation. Consider it high energy x-rays. It usually is with other types of radiation.

$${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + {}^{0}_{0}\gamma$$

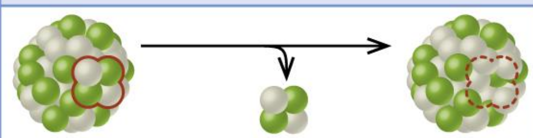
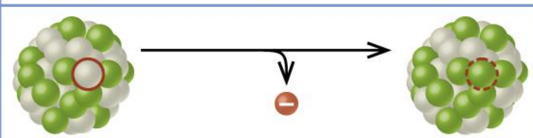
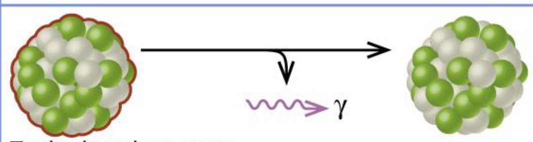
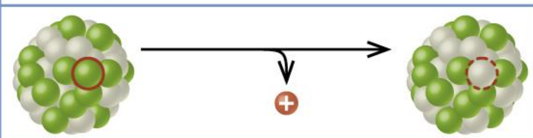
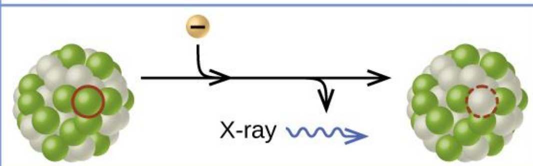
The positron which is the antiparticle of an electron. ${}^{0}_{+1}e$

$${}^{30}_{15}P \rightarrow {}^{30}_{14}Si + {}^{0}_{+1}e$$

The electron capture of an electron. ${}^{0}_{-1}e$

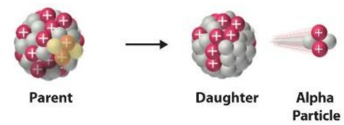
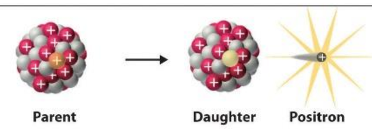
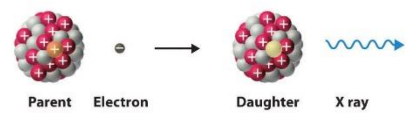
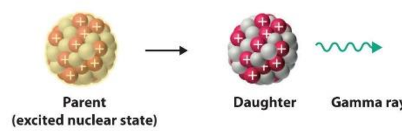
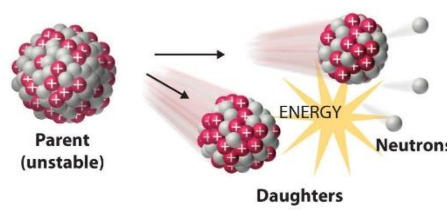
$${}^{92}_{44}Ru + {}^{0}_{-1}e \rightarrow {}^{92}_{43}Tc$$

The table below shows the mass number, A, which is the number of protons and neutrons. And Z, the atomic number which is the number of protons. To find the number of neutrons it is the mass number (Z) minus the atomic number (A). Notice the mass number decreases by 4 in the alpha decay. And the atomic number decrease by 2. Knowing this means you can solve nuclear equation problems on the worksheet.

Type	Nuclear equation	Representation	Change in mass/atomic numbers
Alpha decay	$^{A}_{Z}X \quad ^{4}_{2}He + ^{A-4}_{Z-2}Y$		A: decrease by 4 Z: decrease by 2
Beta decay	$^{A}_{Z}X \quad ^{0}_{-1}e + {}_{Z+1}^{A}Y$		A: unchanged Z: increase by 1
Gamma decay	$^{A}_{Z}X \quad ^{0}_{0}\gamma + ^{A}_{Z}Y$		A: unchanged Z: unchanged
Positron emission	$^{A}_{Z}X \quad ^{0}_{+1}e + {}_{Y-1}^{A}Y$		A: unchanged Z: decrease by 1
Electron capture	$^{A}_{Z}X \quad ^{0}_{-1}e + {}_{Y-1}^{A}Y$		A: unchanged Z: decrease by 1

A is mass number. Z is atomic number.

Here is another table showing the different radiation types.

Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	$^{4}_{2}\alpha$	$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$	
Beta decay	$^{0}_{-1}\beta$	$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}X' + {}^{0}_{-1}\beta$	
Positron emission	$^{0}_{+1}\beta$	$^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}X' + {}^{0}_{+1}\beta$	
Electron capture	X rays	$^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}^{A}_{Z-1}X' + \text{X ray}$	
Gamma emission	$^{0}_{0}\gamma$	$^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma$	
Spontaneous fission	Neutrons	$^{A+B+C}_{Z+Y}X \longrightarrow {}^{A}_{Z}X' + {}^{B}_{Y}X' + C\,{}^{1}_{0}n$	

Particle Changes

- Beta Emission – neutron changing into a proton

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

- Positron Emission – proton changing into a neutron

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

- Electron Capture – proton changing into a neutron

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

Tro: Chemistry: A Molecular Approach 19

As you can see there are protons changing into neutrons, and neutrons changing into protons for some of the nuclear reactions. This is one of the reasons there is transmutation which is the formation of a new element from radioactivity.

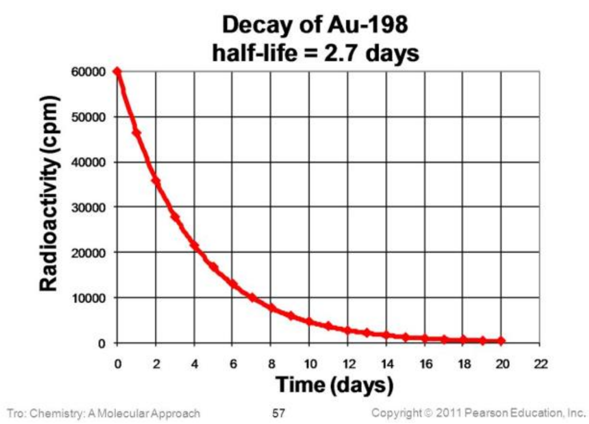
Characteristics of the Various Types of Radiation

	Alpha	Beta	Gamma
Symbol	$^{4}_{2}He$	$^{0}_{-1}\beta$ or $^{0}_{-1}e$	$^{0}_{0}\gamma$
Shielding	Easy (skin, clothes, paper)	Medium (aluminum foil)	Difficult (lead, concrete)
Energy	High	Medium	Low
Biological Hazard	High	Medium	Low-Medium
Actual Hazard	Low	Medium	High

Many people are curious about which kind of radiation is harmful and they all are, but to different degrees. Alpha, beta and gamma have different levels of ionizing power and penetrability. The ionization power is what damages the cells. Alpha has the highest energy but is stopped easily with clothes. Gamma penetrates deeply so it reaches the cells easily. Even though it has low energy it is the worst of all the radiation emitted.

Half-life

The trend of the radioactivity half-life can be predicted, but the time any particular nuclide would decay cannot.



Half-life is the time it takes for one-half of the parent nuclides in a radioactive sample to decay to the daughter nuclides. The radioactive gold in this graph has a half-life of 2.7 days. So every 2.7 days the population decrease by one-half. That trend is the recognizable exponential decay curve.

Every different nuclide has a different half-life. Some are seconds and some are millions of years. Also most of the time the radioactive atom decays into another radioactive atom which has its own half-life.

Uranium goes from U-238 to Pb-206 through a series of decay. Only when the atom reaches the end of the series is the nuclide stable! See the diagram below.

Uranium decay series