GROUPS: A, E, I

#1

20.2 Nuclear Reactions: Radioactivity

Nuclear versus chemical

Nuclear reactions can change one element into a different element. They can also change an isotope into a different isotope of the same element. Chemical reactions do not change the types of atoms involved. They only rearrange atoms to form different molecular compounds.

Energy of nuclear reactions

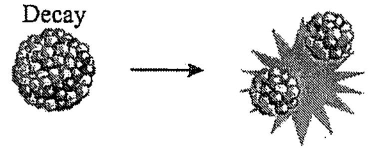
Nuclear reactions involve much more energy than chemical reactions. The energy released by a chemical reaction is related to the rearrangement of the electronic structure of atoms which involves electrical forces. For nuclear reactions the energy released is related to the rearrangement of the atomic nucleus which involves the strong nuclear force, the strongest force in the universe.

Reaction types

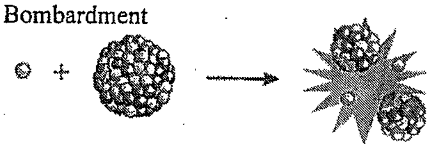
There are two main types of nuclear reactions.

1. Decay reactions: during which a nucleus breaks up (dissintegrates) spontaneously
2. Bombardment reactions: during which a nucleus is struck by another nucleus or some nuclear particle such as a proton or a neutron.

Decay



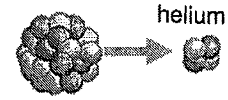
Bombardment



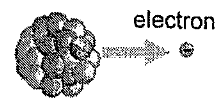
Radioactivity

The four most common types of nuclear decay are: alpha (α) decay, beta (β) decay, gamma (γ) decay, and positron emission (β^+) decay. The elements that decay by α, β, γ, β^+ decay are said to be radioactive. Alpha, beta and positron emission decay release energy that is carried by particles. Gamma decay releases electromagnetic energy. Light, radio waves, microwaves and x-rays are forms of electromagnetic energy. **Radioactivity** is a general term used to describe the property of some elements to break up and release energy associated with matter or waves.

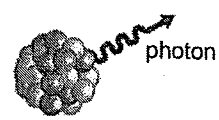
Alpha decay



Beta decay



Gamma decay



Radiation

The transmission of energy, matter or waves, through space is called **radiation**. Radiation can be dangerous if it has high enough energy to break chemical bonds in molecules. Exposure to radiation over a long period of time can be harmful. Ultraviolet radiation from the sun is an example of radiation that can be harmful to living organisms.

Chemistry terms

nuclear reactions - involve the nuclei and may change one element into another.
radioactivity - property of some element to break up and release energy.
radiation - the transmission of energy through space.

KEY: yellow highlighter = facts
red pen = confusing things
orange highlighter = vocab

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GROUPS: B, F, 4

#2

Decay Reactions: Alpha Decay

Alpha decay

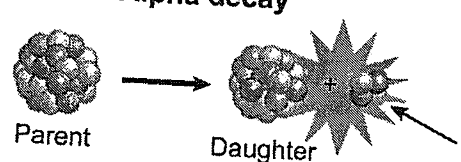
In **alpha decay** the original nucleus ejects two protons and two neutrons which is the nucleus of helium-4, ${}^{4}_{2}He$, also called alpha (α) particle. During alpha decay the emitted radiation is also called **alpha radiation** which is a fast moving ${}^{4}_{2}He$ nucleus.

Uranium-238 decays by releasing an α particle, ${}^{4}_{2}He$, and thorium-234, ${}^{234}_{90}Th$.

The original uranium atom is called the **parent nuclide** and the thorium atom is called the **daughter nuclide**.

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

Alpha decay



Protons	Decrease by 2
Neutrons	Decrease by 2
Atomic number	Decrease by 2
Mass number	Decrease by 4

alpha particles deposit their energy over small distances

When the α particle hits a molecule it transfers energy to it and damages it. Damaged molecules in the cells of biological systems may result in cell death or the abnormal reproduction of cells. Since the α particles are very large, their ability to penetrate into matter is very limited. α radiation can be stopped by a sheet of paper. If an element that undergoes α decay is ingested it is very dangerous. As the α source is carried throughout the body the emitted α particles are in direct contact with the molecules in the cells of organs and can deposit their energy causing great damage.

Solved problem

Write the complete nuclear equation for the α decay of radium isotope ${}^{226}_{88}Ra$.

Relationships: *We need to find the type of the daughter nucleus X, the atomic number Z and the mass number A.* ${}^{226}_{88}Ra \rightarrow {}^{A}_{Z}X + {}^{4}_{2}He$

Solve: *First: Balance the atomic number and the mass number.*

- *By balancing the mass number we obtain A=222*
- *By balancing the atomic number we obtain Z=86*

Second: Look at the periodic table to determine the identity of the unkown daughter element.

- *Since the atomic number is 86 the daughter nuclide is radon (Rn).*

Answer: *The complete α decay equation is* ${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$

Chemistry terms

alpha decay - happens when a nucleus decays by releasing a helium nucleus.
alpha radiation - the radiation associated with alpha decay.
parent nuclide - the original nucleus involved in a nuclear reaction.
daughter nuclide - the nucleus resulting from a nuclear reaction.

Key: yellow highlighter = facts
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GROUPS: C, G

#3

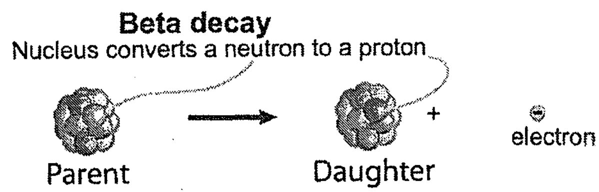
Beta Decay

Beta decay

Beta decay happens when an unstable nucleus emmits an electron. We know that the nucleus does not have any electrons in it. So where does the emitted electron during beta decay come from? It turns out that the electron is formed when a neutron in the nucleus changes into a proton and an electron. The radiation released during beta decay is called **beta radiation**.

Beta particle is an electron

Since the charge of the nucleus increases by +1 as the neutron changes to a proton, the formation of the electron, which has a charge of -1, maintains the overall charge of the nucleus. The electron released during beta decay is called beta particle.



Beta symbol $^{0}_{-1}e$

The beta (β) particle is an electron. For consistency with the genral nuclide symbol and in order to help us with the balance of mass and atomic numbers the β particle is written with the symbol $^{0}_{-1}e$.

$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

Radium $^{228}_{88}Ra$ could also decay by β-decay according to: $^{226}_{88}Ra \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}e$

Solved problem

Write the complete nuclear equation for the β decay of Radium isotope $^{228}_{88}Ra$

Given: *The parent nuclide and the type of reaction*

Relationships: *We need to find the type of the daughter nucleus X, the atomic number Z and the mass number A.* $^{228}_{88}Ra \rightarrow {}^{A}_{Z}X + {}^{0}_{-1}e$

Solve: *First: Balance the atomic number and the mass number.*

- *By balancing the mass number we obtain A = 228*
- *By balancing the atomic number we obtain 88 = Z-1 or Z = 89*

Second: Look at the periodic table to determine the identity of the unkown daughter element.

- *The atomic number is 89 and the daughter nuclide is actinium, Ac.*

Answer: *The complete β decay equation is* $^{228}_{88}Ra \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}e$

Chemistry terms

beta decay - when an unstable nucleus releases an electron.

beta radiation - the radiation resulting from beta decay.

Key: yellow highlighter = facts
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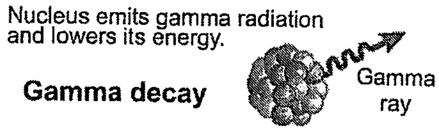
Groups: D, H

#4

Gamma Decay, Positron Emission

Gamma decay Radioactive decay may also happen with the emission of electromagnetic radiation. **Gamma decay**, abreviated γ-decay, happens when an excited nucleus goes to a lower energy state by emitting high energy electromagnetic radiation. The wavelength of this radiation is about 10^{-12} m. In some cases the emission of γ radiation, also called γ-rays and denoted by $^{0}_{0}\gamma$, follows some other radioactive decay such as β-decay or α-decay.

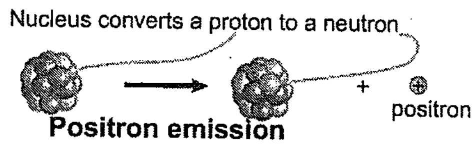


Protons	Stay the same
Neutrons	Stay the same
Atomic number	Stays the same
Mass number	Stays the same

γ-ray energy The number of protons and neutrons does not change during γ-decay. Gamma radiation has high enough energy (greater than 10^{-13} joules per disintegration) to break apart other atoms making them dangerous to living organisms. The best way to stop γ-rays is by using a thick shielding material made of lead or concrete.

Positron **Positron**, denoted with the symbol $^{0}_{+1}e$ in nuclear equations, is a nuclear particle that has the same mass as the electron, but it has a positive charge.

Positron emission Nuclear decay by **positron emission** happens when an unstable nucleus emits a positron. In doing so it converts a proton into a neutron.



Protons	Decrease by 1
Neutrons	Increase by 1
Atomic number	Decreases by 1
Mass number	Stays the same

Solved problem

Determine the type of decay for the reactions:

1) $^{234}_{90}Th \rightarrow ^{234}_{90}Th + ^{A1}_{Z1}X1$. 2) $^{95}_{43}Tc \rightarrow ^{95}_{42}Mo + ^{A2}_{Z2}X2$

Given: *We are given the mass and atomic numbers of the parent and daughter nuclides. Balance the equations to find unknowns X1 and X2.*

Solve: *Balance the atomic numbers to find Z and mass numbers to find A*

- *For reaction 1: 234 = 234 + A1, A1=0. And 90 = 90 + Z1, Z1=0*
- *For reaction 2: 95 = 95 + A2, A2=0. And 43 = 42 + Z2, Z2=+1*

Answer: *For reaction 1:* $^{A1}_{Z1}X1 = ^{0}_{0}X1$ *which denotes γ-decay.* $^{A1}_{Z1}X1 = ^{0}_{0}\gamma$

For reaction 2: $^{A2}_{Z2}X2 = ^{0}_{+1}X2$ *denotes positron decay.* $^{A2}_{Z2}X2 = ^{0}_{+1}e$.

Chemistry terms

gamma decay - when a nucleus decays releasing electromagnetic energy.
positron - a particle that has the same mass as the electron and positive charge.
positron emission - when a nucleus decays by releasing a positron.

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