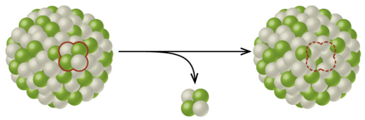
Introduction to Physical Science

Radioactive Decay

Presented by Robert Wagner

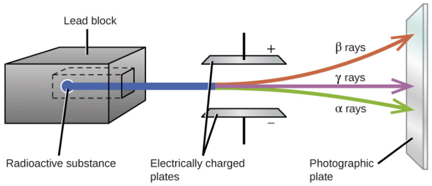
Radioactive Decay

- The spontaneous change of an unstable nuclide into another
- Parent nuclide: Unstable nuclide
- Daughter nuclide: Result of the decay process
  - Daughter will lie closer to the band of stability - however, it may be stable or unstable itself



Types of Radioactive Decay Particles

- α-particles - helium nucleus
  - Positively charged
- Β-particles - electron
  - Negatively charged
- γ-rays - electromagnetic waves
  - No charge



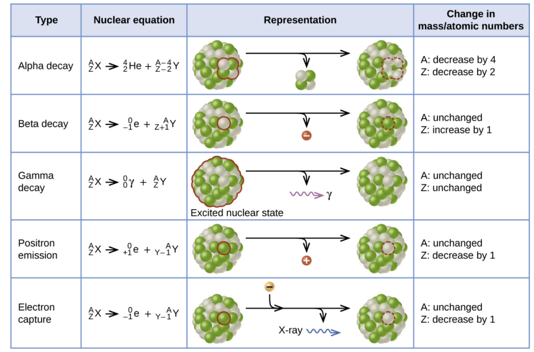
Types of Radioactive Decay

- Alpha(α) decay
  - Emission of an alpha particle from the nucleus
  - Primarily occurs with very heavy nuclei
- Beta (Β) decay
  - Neutron converted into a proton and an electron (beta particle)
  - Occurs when there is a large neutron to proton ratio
- Gamma (γ) emission
  - Nucleus is in an excited state
- Positron ($Β^+$) emission
  - Emission of a positron from a nucleus
  - Occurs when there is a small neutron to proton ratio
- Electron capture
  - Inner electron is captured
  - Combines with a proton to form a neutron

Types of Radioactive Decay (Examples)

- Alpha(α) decay
  -
- Beta (β) decay
  -
- Gamma (γ) emission
  -
- Positron (β^+) emission
  -
- Electron capture
  -

Types of Radioactive Decay (Chart)



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

Image Credit: OpenStax Chemistry Figure 21.7 CC BY 4.0

Radioactive Decay Series

- A chain of successive disintegrations
  - Form a radioactive family or radioactive decay series
  - Ultimately leads to a stable end product
- Example series
  - Uranium series
  - Actinide series
  - Thorium series

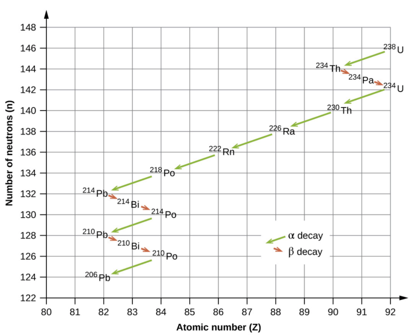


Image Credit: OpenStax Chemistry Figure 21.9 CC BY 4.0

Radioactive Half-Lives

- Each radioactive nucleus has a characteristic half-life
  - Amount of time it takes from one half of the radioactive material to decay
- Half-life calculations can be done using natural logarithms and exponentials
  - We will look at other methods for this class

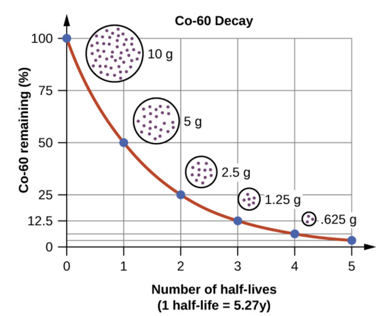


Image Credit: OpenStax Chemistry Figure 21.10 CC BY 4.0

Example

20g of Co-60 ; Half-life= 5.27 years

Time	Parent	Daughter	Ratio
0 yr	20g	0g	0
5.27 yr	10g	10g	1:1
10.54 yr	5g	15g	3:1
15.81 yr	2.5g	17.5g	7:1
21.08 yr	1.25g	18.75g	15:1
26.35 yr	0.625g	19.375g	31:1

- How long will it take 20g of Cobalt-60 (Half-life = 5.27 years) to decay into 5g?
- How much would be left if we wait the same additional amount of time after the first decay from 20g -> 5g?
- When would the ratio of daughter to parent by about 5:1?

Radiometric Dating

- Can use this to determine ages of objects that contain radioactive materials
- Carbon-14 dating
  - Carbon-14 forms in the atmosphere from the interaction of nitrogen with cosmic rays
  -
- Carbon-14 is incorporated into living organisms as the carbon
  - Decays with a half-life of 5730 years

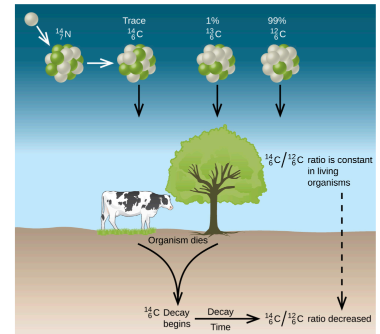


Image Credit: OpenStax Chemistry Figure 21.11 CC BY 4.0

Radiometric Dating (2)

- Can only use Carbon-14 dating for things containing carbon
  - Half-life would be too short to date things like rocks
- Use other methods to date rocky materials
  - U-238:Pb-206 (4.5 billion year half-life)
  - K-40:Ar-40 (1.25 billion year half-life)

Example

- A moon rock is found to have a Ar-40:K-40 ratio of 11:1. Approximately how old is the rock?
- Start with 100g of K-40.

100g of K-40 ; Half-life= 1.25 billion years

Half-lives	Time	Parent	Daughter	Ratio
0	0 yr	100g	0g	0
1	1.25 Gyr	50g	50g	1:1
2	2.50 Gyr	25g	75g	3:1
3	3.75 Gyr	12.5g	87.5g	7:1
4	5.00 Gyr	6.25g	93.75g	15:1
5	6.25 Gyr	3.125g	96.875g	31:1

Summary

- Radioactive nuclei will spontaneously decay into to other nuclei
- We considered five different types of radioactive decay (alpha, beta, gamma, electron capture, & positron emission)
- Radioactive materials have half-lives which can be used to determine ages of objects