CHM 101
Radioactivity

Reference:

General Chemistry
Principles and Modern Applications TENTH EDITION,
Pearson Canada
Toronto

Content

- Radioactivity
- Naturally Occurring Radioactive Isotopes
- Nuclear Reactions and Artificially Induced Radioactivity
- Rate of Radioactive Decay
- Nuclear Stability
- Nuclear Fission
- Nuclear Fusion

Background

- Traditional Chemistry
  - Reactions occur due to interactions between valence electrons (surrounding nucleus)

- Late 1800s – Early 1900s → New Developments
  - Discovery that Uranium emits radiation (Henry Becquerel)
  - Amount of radiation emitted is proportional to amount of element present (Marie Curie)
  - **"Radioactive"** substances = radiation-emitting (Curie)
  - Radioactivity = a inherent property of certain **ATOMS**, as opposed to a chemical property of compounds (Curie)

- Birth of nuclear chemistry

The Discovery of Radioactivity (1895 – 1898):

- Rountgen found that invisible rays were emitted when electrons hit the surface of a fluorosent screen (discovered x-rays)
- Becquerel accidently discovered that phosphorescent uranium rock produced spots on photographic plates

The Discovery of Radioactivity (1895 – 1898):

- Marie and Pierre Curie isolated the components (uranium atoms) emitting the rays.
- Radioactivity – process by which atoms give off rays or particles.
- Radiation – the penetrating rays and particles emitted by a radioactive source.

The Discovery of Radioactivity (1895 – 1898):

Marie Curie, continued

- identified 2 new elements, Polonium and Radium on the basis of their radioactivity.
- These findings contradicted Dalton's theory of indivisible atoms.

Chemical vs. Nuclear Reactions

Chemical Reactions	Nuclear Reactions
Bonds are broken	Nuclei emit particles and/or rays
Atoms are rearranged	Atoms change into atoms of different element
Involve valence electrons	Involve protons, neutrons, and/or electrons
Small energy changes	Large energy changes
Reaction rate can be changed.	Reaction rate cannot be changed

- Isotopes – atoms of the same element with different numbers of neutrons.
- Radioisotopes – isotopes of atoms with unstable nuclei (too many or too few neutrons).
- Radioactive decay – when unstable nuclei lose energy by emitting radiation to become more stable

Nuclear Stability

- How can a stable nucleus exist?
  - Net positive charge in nucleus surrounded by negative charges (electrons)
  - Electrostatic force
    - Opposite charges attract
    - Like charges repel
  - Why doesn’t the nucleus break apart?
- **Nuclear Force (1934)**
  - Force between protons and neutrons than binds nucleus together within atom
  - Very strong (must be!)

Which Elements/Isotopes Are Radioactive?

- Based on the nuclear force and nuclear stability
  - More protons in nucleus → more neutrons needed to bind nucleus together
  - Critical Factor = **Neutral-to-Proton Ratio**
    - Neutron-to-Proton ratios of stable nuclei increase with increasing atomic number
    - Unstable neutron-to-proton ratio = **RADIOACTIVE**
  - Nuclei with **atomic numbers ≥ 84** = ALWAYS Radioactive
    - Very large nuclei!
    - Neutron-to-proton ratio always unstable

Spontaneous Nuclear Reactions

Radiation and Radioactive Decay

- Unstable (radioactive) nuclei emit radiation (energy) in order to become more stable

- **Radioactive Decay** – occurs when a nucleus spontaneously decomposes in this way

- 3 Common Types of Nuclear Reactions
  - Alpha Radiation
  - Beta Radiation
  - Gamma Radiation

Alpha radiation

- Composition – Alpha particles, same as helium nuclei
- Symbol – Helium nuclei, ${}^{4}_{2}He$, α
- Charge – 2+
- Mass (amu) – 4
- Approximate energy – 5 MeV
- Penetrating power – low (0.05 mm body tissue)
- Shielding – paper, clothing

Alpha Radiation: Nuclear Equation

mass number	238		234	+ 4	=	238
	$^{238}_{92}U$	$\longrightarrow$	$^{234}_{90}Th$	$+\ ^{4}_{2}He$		
atomic number	92		90	+ 2	=	92

$$^{A}_{Z}X \longrightarrow\ ^{A-4}_{Z-2}Y +\ ^{4}_{2}He$$

- Emission of 2 protons and 2 neutrons (as an **<u>alpha particle</u>**, $^{4}_{2}He$) from radioactive atom's nucleus
- Atom's atomic mass decreases by 4 units
- Atom's atomic number decreases by 2 units (**<u>a different element!</u>**)

Beta radiation

- Composition – Beta particles, same as an electron
- Symbol – e^-, $^{0}_{-1}\beta$
- Charge – 1-
- Mass (amu) – 1/1837 (practically 0)
- Approximate energy – 0.05 – 1 MeV
- Penetrating power – moderate (4 mm body tissue)
- Shielding – metal foil

Beta negative Radiation: **Nuclear Equation**

mass number	131		131	+	0	=	131
	$^{131}_{53}I$	$\longrightarrow$	$^{131}_{54}Xe$	+	$^{0}_{-1}e$		
atomic number	53		54	+	(-1)	=	53

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

- Conversion of a neutron into a proton and an electron, followed by the emission of the electron (**beta particle**) from the nucleus
- Atom's atomic mass does NOT change
- Atom's atomic number increases by 1 units (**a different element!**)

Gamma radiation

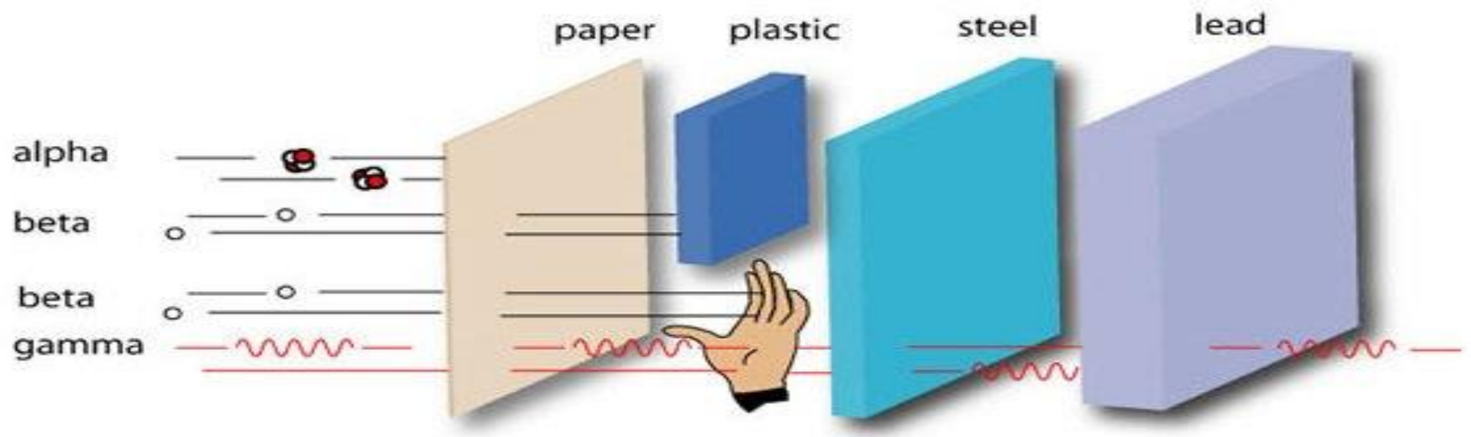
- Composition – High-energy electromagnetic radiation
- Symbol – $^{0}_{0}\gamma$
- Charge – 0
- Mass (amu) – 0
- Approximate energy – 1 MeV
- Penetrating power – high (penetrates body easily)
- Shielding – lead, concrete

Review

Type of Radioactive Decay	Particle Emitted	Change in Mass #	Change in Atomic #
Alpha	α $^{4}_{2}He$	-4	-2
Beta	β $^{0}_{-1}e$	0	+1
Gamma	γ	0	0

Relative Penetrating Power of Radiation Types

- Alpha radiation has low energy and little penetrating power compared to beta radiation
- Gamma has the most energy and penetrating power

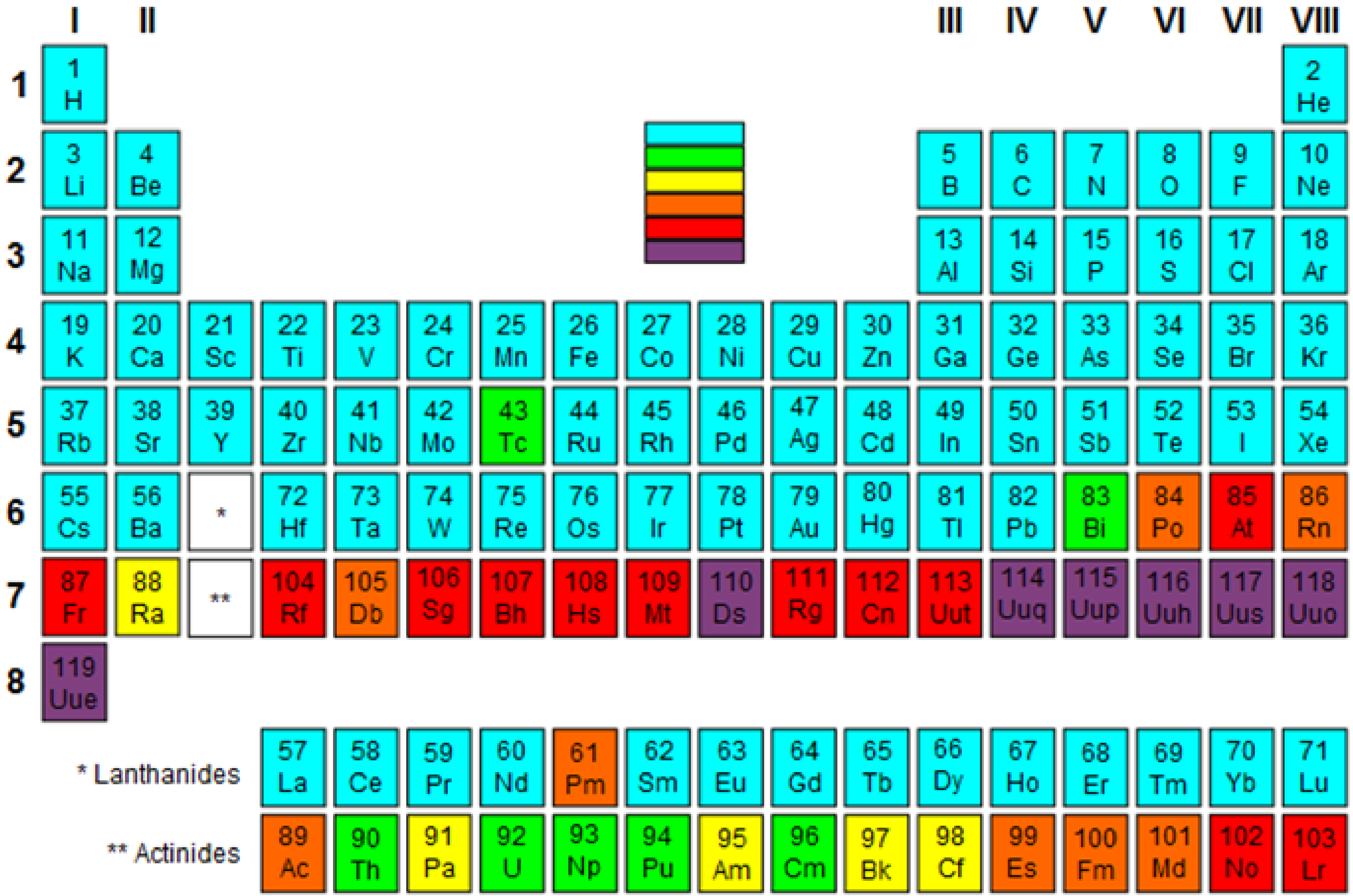


Half-Life

- Half time is the time required for   half of a radioisotope's nuclei to decay into its products.
- For any radioisotope,

# of ½ lives	% Remaining
0	100%
1	50%
2	25%
3	12.5%
4	6.25%
5	3.125%
6	1.5625%

Different Elements → Different Half-Lives



Data for most stable isotope of element

- Stable elements.
- Radioactive elements with half-lives of over four million years.
- Half-lives between 800 and 34,000 years.
- Half-lives between 1 day and 103 years.
- Half-lives ranging between a minute and 1 day.
- Half-lives less than a minute.

Half-Life

initial mass

$$m_t = m_0 \times (0.5)^n$$

mass remaining

of half-lives

Stimulated Nuclear Reactions

Nuclear Fission

- **Fission-splitting** of a nucleus
- - Very heavy nucleus is split into two approximately equal fragments.
- - **Chain** reaction releases several neutrons which **split** more nuclei
- - If controlled, energy is released **slowly** (like in nuclear reactors) Reaction control depends on reducing the speed of the neutrons (increases the reaction rate) and absorbing extra neutrons (decreases the reaction rate).

Nuclear Fusion

- - **Fusion**: Combining of two nuclei
- - Two **light** nuclei combine to form a **single** heavier nucleus
- - Does not occur under standard conditions (positive nuclei repel each other)
- - **Advantage**s compared to **fission** – No radioactive waste, inexpensive
- - **Disadvantages** - requires **large** amount of energy to start, difficult to **control**
- - **Examples** – energy output of stars, hydrogen bomb, future nuclear power plants