

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 accidentally 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 that 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 = **Neutron-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

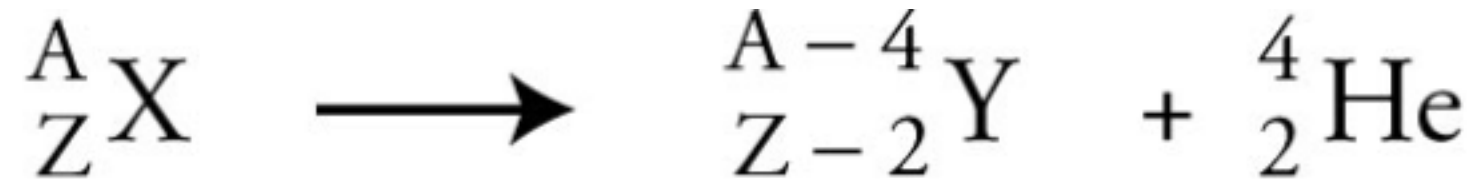
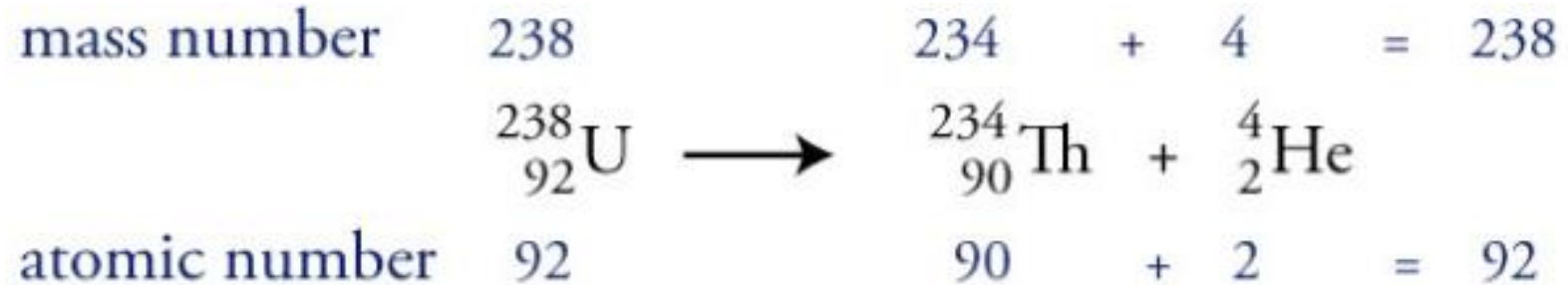
Radiation and Radioactive Decay

- 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, ${}^4_2\text{He}$, 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

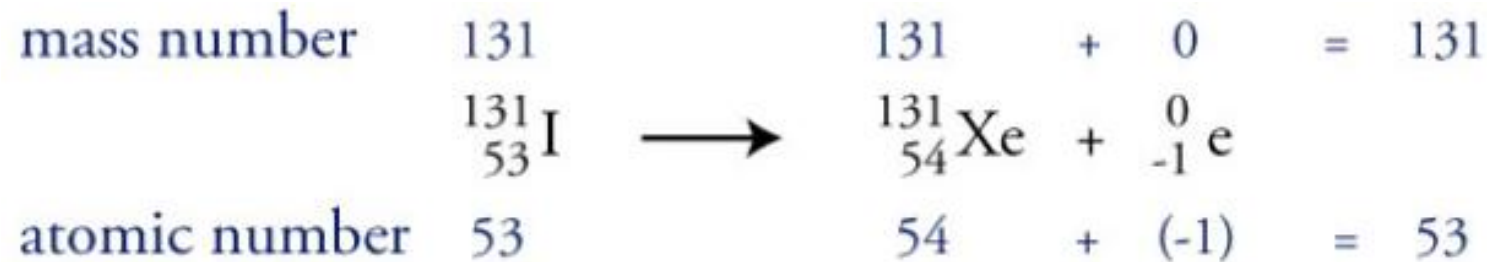


- Emission of 2 protons and 2 neutrons (as an **alpha particle**, ${}_2^4\text{He}$) from radioactive atom's nucleus
- Atom's atomic mass decreases by 4 units
- Atom's atomic number decreases by 2 units (**a different element!**)

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



- 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

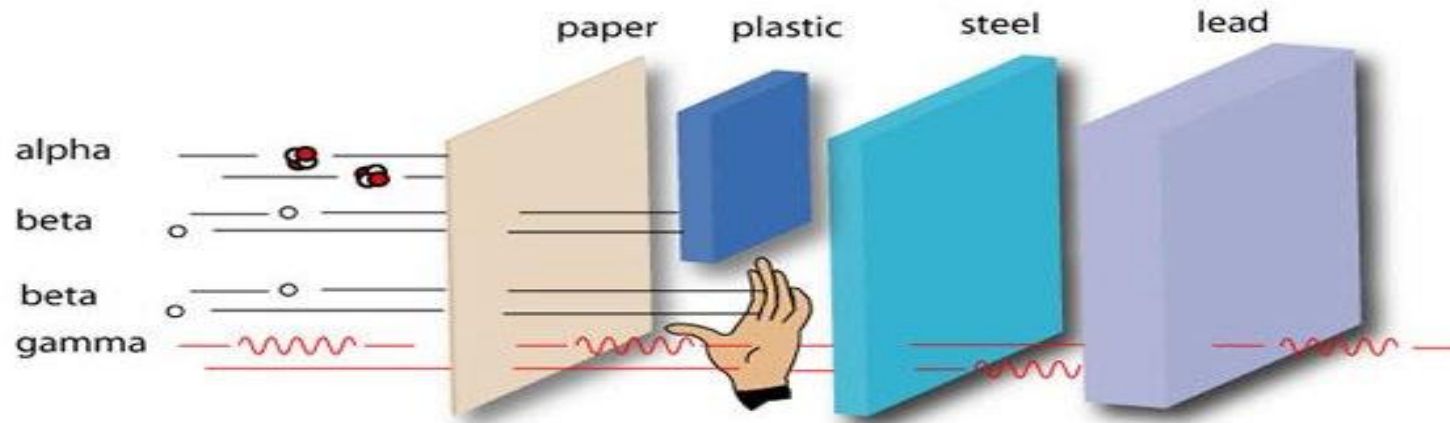
- Composition – High-energy electromagnetic radiation
- Symbol – ${}^0_0\gamma$
- Charge – 0
- Mass (amu) – 0
- Approximate energy – 1 MeV
- Penetrating power – high (penetrates body easily)
- Shielding – lead, concrete

Review

Type of Radioactive Decay	Particle Emitted	Change in Mass #	Change in Atomic #
Alpha	$\alpha \quad {}^4_2\text{He}$	-4	-2
Beta	$\beta \quad {}^0_{-1}\text{e}$	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 $\frac{1}{2}$ 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

	I		II												III	IV	V	VI	VII	VIII
1	1 H																			2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne		
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar		
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr		
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe		
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn		
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo		
8	119 Uue																			
	* Lanthanides			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
	** Actinides			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

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)
- - **Advantages** 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