Nuclear Reactions: Chemistry

5.1 AN INTRODUCTION TO NUCLEAR CHEMISTRY
Discovery of Radioactivity
In 1895 Wilhelm Konrad Roentgen discovered X-rays.

Roentgen observed that a vacuum discharge tube enclosed in a thin, black cardboard box had caused a nearby piece of paper coated with the salt barium platinocyanide to phosphorescence.
Roentgen

From this and other experiments he concluded that certain rays, which he called X-rays, were emitted from the discharge tube, penetrated the box, and caused the salt to glow.
Shortly after Roentgen’s discovery, Antoine Henri Becquerel attempted to show a relationship between X-rays and the phosphorescence of uranium salts.

Becquerel wrapped a photographic plate in black paper, sprinkled a sample of a uranium salt on it, and exposed it to sunlight.
When Becquerel attempted to repeat the experiment the sunlight was intermittent.

- He took the photographic plate wrapped in black paper with the uranium sample on it, and placed the whole setup in a drawer.
Several days later he developed the film and was amazed to find an intense image of the uranium salt on the plate.

He repeated the experiment in total darkness with the same result.
Radioactivity is the spontaneous emission of particles and/or rays from the nucleus of an atom. This proved that the uranium salt emitted rays that affected the photographic plate, and that these rays were not a result of phosphorescence due to exposure to sunlight.

One year later, in 1896, Marie Curie coined the name radioactivity. Elements having this property are radioactive.
In 1899 Rutherford began to investigate the nature of the rays emitted by uranium.

- He found two particles in the rays. He called them *alpha* and *beta* particles.
- Rutherford’s nuclear atom description led scientists to attribute the phenomenon of radioactivity to reactions taking place in the nuclei of atoms.
- In 1899, when testing Uranium, he realized it emitted particles changing into another element.
The gamma ray, a third type of emission from radioactive material, was discovered by Paul Villiard in 1900.
Definitions
Natural Radioactivity
• Radioactive elements continuously undergo radioactive decay or disintegration to form different elements.

• Radioactivity is a property of an atom’s nucleus. It is not affected by temperature, pressure, chemical change or physical state.
radioactive decay  the process by which a radioactive element emits particles or rays and is transformed into another element.
Each radioactive nuclide disintegrates at a specific and constant rate, which is expressed in units of half-life.

The half-life ($t_{1/2}$) is the time required for one-half of a specific amount of a radioactive nuclide to disintegrate.

$1.0 \text{ g } ^{226}_{88} \text{Rn} \overset{t_{1/2}}{\longrightarrow} 0.5 \text{ g } ^{226}_{88} \text{Rn} \overset{t_{1/2}}{\longrightarrow} 0.25 \text{ g } ^{226}_{88} \text{Rn}$

1620 yrs 1620 yrs
The half-life of $^{131}\text{I}$ is 8 days. How much $^{131}\text{I}$ from a 32-g sample remains after five half-lives?

Trace a horizontal line from this point on the plotted line to the y-axis and read the corresponding grams of $^{131}\text{I}$. 

half-lives: 5

number of days: 40

amount remaining: 8 g
- Nuclides are said to be either stable (nonradioactive) or unstable (radioactive).

- Elements that have an atomic number greater than 83 are naturally radioactive.

- Some of the naturally occurring nuclides of elements 81, 82 and 83 are radioactive and some are stable.
<table>
<thead>
<tr>
<th>Date</th>
<th>I-131</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/14</td>
<td>2760</td>
</tr>
<tr>
<td>1/15</td>
<td>2612</td>
</tr>
<tr>
<td>1/16</td>
<td>2383</td>
</tr>
<tr>
<td>1/17</td>
<td>2287</td>
</tr>
<tr>
<td>1/18</td>
<td>2088</td>
</tr>
<tr>
<td>1/21</td>
<td>1542</td>
</tr>
<tr>
<td>1/23</td>
<td>1322</td>
</tr>
<tr>
<td>1/24</td>
<td>1226</td>
</tr>
<tr>
<td>1/25</td>
<td>1166</td>
</tr>
<tr>
<td>1/29</td>
<td>819</td>
</tr>
<tr>
<td>1/30</td>
<td>737</td>
</tr>
<tr>
<td>1/31</td>
<td>684</td>
</tr>
<tr>
<td>2/1</td>
<td>600</td>
</tr>
<tr>
<td>2/5</td>
<td>512</td>
</tr>
<tr>
<td>2/6</td>
<td>403</td>
</tr>
<tr>
<td>2/7</td>
<td>385</td>
</tr>
<tr>
<td>2/8</td>
<td>343</td>
</tr>
<tr>
<td>2/11</td>
<td>263</td>
</tr>
<tr>
<td>2/12</td>
<td>255</td>
</tr>
<tr>
<td>Isotope</td>
<td>Half-life</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>Ra-223</td>
<td>11.7 days</td>
</tr>
<tr>
<td>Ra-224</td>
<td>3.64 days</td>
</tr>
<tr>
<td>Ra-225</td>
<td>14.8 days</td>
</tr>
<tr>
<td>Ra-226</td>
<td>1620 years</td>
</tr>
<tr>
<td>Ra-228</td>
<td>6.7 years</td>
</tr>
</tbody>
</table>
Alpha Particles, Beta Particles and Gamma Rays
Marie Curie, in a classic experiment, proved that alpha and beta particles are oppositely charged.

Alpha rays are less strongly deflected to the negative pole.

Beta rays are strongly deflected to the positive pole.

Gamma rays are not deflected by the magnet.

Three types of radiation are detected by a photographic plate.
An alpha particle is a helium nucleus.

It consists of two protons and two neutrons.

It has an atomic number of 2.

It has a mass of 4 amu.

The symbols of an alpha particle are $^4_2\text{He}$ and $a$. 
Loss of an alpha particle from the nucleus results in
loss of 4 in the mass number
loss of 2 in the atomic number
Formation of thorium from the radioactive decay of uranium can be written as:

- Mass number decreases by 4

\[ ^{238}\text{U} \rightarrow ^{234}\text{Th} + ^{4}_2\text{He} \]

- Atomic number decreases by 2
To have a balanced nuclear equation
• the sum of the mass numbers (superscripts) on both sides of the equation must be equal.
• the sum of the atomic numbers (subscripts) on both sides of the equation must be equal.

\[
\begin{align*}
\text{sum of mass numbers} &= 238 \\
^{238}_{92}\text{U} &\rightarrow ^{234}_{90}\text{Th} + ^4_2\text{He} \\
\text{sum of atomic numbers} &= 92
\end{align*}
\]
Beta Particles
The symbols of the beta particle are $\beta$. The beta particle is identical in mass and charge to an electron. Its charge is -1.
Loss of a beta particle from the nucleus results in

- no change in the mass number
- an increase of 1 in the atomic number

\[
^{234}_{90}\text{Pb} \rightarrow ^{234}_{91}\text{Pa} + \text{e}^-
\]
The symbol of a gamma ray is \( Y \).

A gamma ray is a high energy photon.

It is emitted by radioactive nuclei.

It has no electrical charge.

It has no measurable mass.
Loss of a gamma ray from the nucleus results in

- no change in the mass number
- no change in atomic number
Write an equation for the loss of an alpha particle from the nuclide $^{194}_{78}$Pt.
Write an equation for the loss of an alpha particle from the nuclide $^{194}_{78}$Pt.

Mass number (sum of protons and neutrons in the nucleus)

Atomic number (number of protons in the nucleus)

A nuclide of platinum

78 protons + 116 neutrons
Write an equation for the loss of an alpha particle from the nuclide $^{194}_{78}\text{Pt}$.

Loss of an alpha particle, $^{4}_{2}\text{He}$, results in a decrease of 4 in the mass number and a decrease of 2 in the atomic number.

Mass of new nuclide: $194 - 4 = 190$

Atomic number of new nuclide: $78 - 2 = 76$

Element number 76 is Os, osmium.

The equation is

$^{194}_{78}\text{Pt} \rightarrow ^{190}_{76}\text{Os} + ^{4}_{2}\text{He}$
What nuclide is formed when $^{228}_{88}$Ra loses a beta particle from its nucleus?
What nuclide is formed when $^{228}_{88}\text{Ra}$ loses a beta particle from its nucleus.

A nuclide of radium

Mass number (sum of protons and neutrons in the nucleus)

Atomic number (number of protons in the nucleus)
What nuclide is formed when $^{228}_{88}\text{Ra}$ loses a beta particle from its nucleus.

The loss of a beta particle from a $^{228}_{88}\text{Ra}$ nucleus means a gain of 1 in the atomic number with no essential change in mass.

Mass of new nuclide: $228 - 0 = 228$

Atomic number of new nuclide: $88 + 1 = 89$

The equation is

$$^{228}_{88}\text{Ra} \rightarrow ^{228}_{89}\text{Ac} + ^{0}_{-1}\text{e}$$
Penetrating Power of Radiation
The ability of radioactive rays to pass through various objects is in proportion to the speed at which they leave the nucleus.

Thin sheet of aluminum – stops α and β particles.

Thin sheet of paper – stops α particles.

5-cm lead block – will reduce, but not completely stop γ radiation.
<table>
<thead>
<tr>
<th>Radiation</th>
<th>Symbol</th>
<th>Mass (amu)</th>
<th>Electrical charge</th>
<th>Velocity</th>
<th>Composition</th>
<th>Ionizing power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>$\alpha, {}_2^4\text{He}$</td>
<td>4</td>
<td>+2</td>
<td>Variable, less than 10% the speed of light</td>
<td>He nucleus</td>
<td>High</td>
</tr>
<tr>
<td>Beta</td>
<td>$\beta, {}_1^0\text{e}$</td>
<td>$\frac{1}{1837}$</td>
<td>−1</td>
<td>Variable, up to 90% the speed of light</td>
<td>Identical to an electron</td>
<td>Moderate</td>
</tr>
<tr>
<td>Gamma</td>
<td>$\gamma$</td>
<td>0</td>
<td>0</td>
<td>Speed of light</td>
<td>Photons or electromagnetic waves of energy</td>
<td>Almost none</td>
</tr>
</tbody>
</table>
Shielding Radiation

- Heavy clothing, wood
- Lead, concrete
- Paper, clothing, skin
- Beta particles
- Alpha particles
- Gamma rays
Radioactive Disintegration Series
The uranium disintegration series. $^{238}_{92}U$ decays by a series of alpha ($\alpha$) and beta ($\beta$) emissions to the stable nuclide $^{206}_{82}Pb$. 
The End