CHAPTER 21: Nuclear Chemistry

**Isotopes** - atoms of the same element that differ in the number of neutrons

Writing Symbols for isotopes

\[ A(\text{mass number})_X \]

**Nucleon** - nuclear particles (neutron or proton)

**Radioactivity** - the
spontaneous emission of particles and energy from atomic nuclei.

alpha emission
beta emission
gamma emission
positron emission
electron capture

<table>
<thead>
<tr>
<th>TABLE 21.1 Properties of Alpha, Beta, and Gamma Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Charge</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Relative penetrating power</td>
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<tr>
<td>Nature of radiation</td>
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</tr>
</tbody>
</table>

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Nuclear Reactions, transmutations, must be balanced with respect to both A and Z.

Consider each of the

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron</td>
<td>$^1_0\text{n}$</td>
</tr>
<tr>
<td>Proton</td>
<td>$^1_1\text{H}$ or $^1_1\text{p}$</td>
</tr>
<tr>
<td>Electron</td>
<td>$^0_{-1}\text{e}$</td>
</tr>
<tr>
<td>Alpha particle</td>
<td>$^4_2\text{He}$ or $^4_2\alpha$</td>
</tr>
<tr>
<td>Beta particle</td>
<td>$^0_{-1}\text{e}$ or $^0_{-1}\beta$</td>
</tr>
<tr>
<td>Positron</td>
<td>$^0_{+1}\text{e}$</td>
</tr>
</tbody>
</table>
above decay routes

**Belt of Stability** - the stable isotopes in a plot of #neutrons vs Z
-too many neutrons, above the belt of stability: beta emission
-too few neutrons, below
the belt of stability: positron emission or electron capture

Stability of Atomic Nuclei
1. Z<20 Stable isotopes have equal numbers of protons and neutrons or just one extra neutron

2. Z>20 \#neutrons/#protons for stable isotopes becomes >1
3. Z>83 all isotopes are radioactive

4. Certain numbers of protons and neutrons have special stability (2, 8, 20, 28, 50, 82) (magic numbers)

<table>
<thead>
<tr>
<th>#prot.</th>
<th>#neut.</th>
<th>#isotopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>even</td>
<td>even</td>
<td>157</td>
</tr>
<tr>
<td>even</td>
<td>odd</td>
<td>52</td>
</tr>
<tr>
<td>odd</td>
<td>even</td>
<td>50</td>
</tr>
<tr>
<td>odd</td>
<td>odd</td>
<td>5</td>
</tr>
</tbody>
</table>
Synthesis of elements

1919

\[ ^{14}\text{N} + ^{4}\text{He} \rightarrow ^{17}\text{O} + ^{1}\text{H} \]

Artificial Elements
Tc, Pm, and Z>92
$^{96}\text{Mo} + ^2\text{H} \rightarrow ^{97}\text{Tc} + ^1\text{n}$

$^{238}\text{U} + ^1\text{n} \rightarrow ^{239}\text{U} \rightarrow ^{239}\text{Np} + ^{-1}\text{e}$

$^{239}\text{Np} \rightarrow ^{239}\text{Pu} + ^{-1}\text{e}$

**Uses of Radioisotopes**

**Dating**

**Medical**

**Diagnostic**

**Treatment**

**Tracer Studies**

**Radiochemical Dating** - the use of naturally occurring
radioisotopes to determine the age of an object.

Rate of Radioactive decay is a first order process.

\[ A \rightarrow B \]

rate = - \frac{d[A]}{dt} = kt

\[ A = A_0 e^{-kt} = 10^{-kt/2.303} ; \]

\[ t_{1/2} = 0.693/k \]
How many half-lives are required for the activity of a sample to decrease to 99.9% of its original value.

Estimate the age of a bone if it contains 1.63µg of $^{14}$C today and contained 14.2 µg when the animal was
alive. The half-live of $^{14}\text{C}$ is 5728 years.

Dating or rocks requires use of other isotopes $^{238}\text{U}$ ($4.5\times 10^9$) or $^{40}\text{K}$ ($1.3 \times 10^9$) years.

A nucleus **ALWAYS** weighs less than the sum of its component particles. (Violation of the Law of Conservation of Mass ?)

mass defect = mass difference between a
nucleus and its component particles

Where did this mass go?
CONVERTED TO ENERGY

\[ E = mc^2 \]

**Nuclear Binding Energy** - the energy required to separate a nucleus into its individual particles.

A plot of Nuclear Binding Energy/nucleon vs A indicates that the most
stable nuclei is $^{56}\text{Fe}$

**Fission** - The splitting of very heavy nuclei to form lighter ones.
released neutrons cause a chain reaction

$$^{235}\text{U} + ^1\text{n} \rightarrow ^{142}\text{Ba} + ^{91}\text{Kr} + 3^1\text{n}$$

ENERGY!!! = $1.68 \times 10^{10}$ kJ
This E can be used in warfare or for peaceful purposes
Use of Nuclear power
France ~78%
USA ~20%
China ~3%

**Fusion** - the combining of lighter nuclei to form larger ones. (SUN)

\[ ^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} + ^1\text{n} \]

ENERGY!!! = $1.69 \times 10^9$ kJ

**Biol. Effects of Radiation**
Somatic
Genetic
**Units of Radiation** (amount vs exposure)

amount

curie, \( \text{Ci}=3.7 \times 10^{10} \text{dps(Bq)} \)
exposure
rad (rad abs dose)
$1.00 \times 10^{-2}$ J/kg (Gy=100 rad)
rem (rötogen equiv. man)
rem = rad x factor (RBE)
factor = 1 for $\gamma$ and $\beta$
factor = 10 for $\alpha$

Why is $\alpha$ so dangerous (hydroxyl radical)

#rem (short term) effect
0-25 little effect
25-50 dec. in wbc
100-200 sig. dec. in wbc
500rem  50% fatal