Radioactivity

Nuclear Structure

- Nucleus is composed of two particles
  1) Proton (+1) ($m = 1.6724 \times 10^{-27}$ kg ~ 931 MeV)
  2) Neutron (0) ($m = 1.6747 \times 10^{-27}$ kg ~ 931 MeV)

- These particles are considered to be two forms of a single particle: the Nucleon.

Nuclear Nomenclature:

$N \equiv$ # of neutrons in the nucleus (neutron number)
$Z \equiv$ ~~Mass~~ Atomic Number (# of protons in nucleus)
$A \equiv$ Mass Number (# of nucleons in nucleus)

$$\therefore \quad A = Z + N$$

Elements are normally written with ~~the~~ this style:

$${}^{A}_{Z}X$$

(note: in periodic table they are ${}^{Z}X$)

$X \equiv$ element
$A \equiv$ Mass Number
$Z \equiv$ Atomic Number

→ Atoms represented in this manner are called <u>Nuclides</u>

To get Neutron Number

$$N = A - Z$$

e.g. - ${}^{4}_{2}He$ - helium, mass = 4 amu, 2 protons, 4 - 2 = 2 neutrons

${}^{141}Ba$ - Barium mass = 141 amu, 57 = 141 - 56 = 85 neutrons amu

a.m.u. ≡ Atomic Mass Unit.

$$1\ amu = \frac{1}{12}\left({}^{12}_{6}C\right)\ mass$$

$\therefore$ 1 electron = 0.00055 amu
1 proton = 1.00727 amu
1 neutron = 1.00866 amu.

~~the~~

Isotopes:

elements with same Atomic Number (Z), but different Mass number (A) (same # protons, different neutron)

tope → protons

e.g.: ${}^{12}_{6}C$ and ${}^{14}_{6}C$, ${}^{15}_{6}C$

${}^{1}_{1}H$ and ${}^{2}_{1}H$, ${}^{3}_{1}H$

Isotones

elements with Different Atomic Number (Z) but the Same Neutron number (N) ($\therefore$ different Mass Numbers) (Same # neutrons, diff. protons)

tone → n-neutron

eg ~~${}^{12}_{6}C$ and ${}^{13}_{7}C$~~

${}^{5}_{2}He$, ${}^{6}_{3}Li$, ${}^{9}_{6}C$

for all, $A - Z = N = 3$

Isobars:

Elements with Different Atomic # (Z), but same Mass # (A) (∵ Different Neutron #)

e.g. – $^{6}_{2}He$, $^{6}_{3}Li$, $^{6}_{4}Be$ bars ↳ b - both

Isomers:

Are elements that have the same number of protons & neutrons, but are in different nuclear energy states.

e.g. $^{4}_{2}He$, $^{4}_{2}He^{*}$

Summary

	Z	N	A
Isotopes	same	Diff	Diff
Isotones	Diff	same	Diff
Isobars	Diff	Diff	Same
Isomers	Same	Same	Same

~~Stable~~ Nuclear Stability

Nuclei are typically stable if they have an even number of protons and an even number of neutrons.

Nuclei with odd numbers of protons or neutrons are less stable.

# protons	# neutrons	# of stable nuclei
even	even	165
even	odd	57
odd	even	53
odd	odd	6

- For low Atomic Number (Z) ~~most~~ stable nuclei, $N \approx Z$ (ie - protons = neutrons) e.g. $^{4}_{2}He$
- As Atomic number increases, stable nuclei have more neutrons than protons (but still usually even numbers)

e.g. Lead: $^{206}_{82}Pb$ 82 - protons, 124 - neutrons

82
124
206

~~In the nucleus,~~

As protons become closer & closer to each other their electrostatic forces act to keep them apart.

- How does the nucleus stay together?

To overcome the electrostatic repulsion of the protons and to keep the nucleus together, The Strong Nuclear Force takes over.

- The Strong Nuclear Force only interacts at distances that are smaller than the atomic nucleus.

- The Strong Force is approx 100 (10^2) times stronger than the electrostatic Force; but only acts at very small distances. (less than the size of the atomic nucleus ($\sim 10^{-10}$ m)

Nuclear Energy Levels:

- As we discussed earlier - electrons can be in different energy levels, or states ~~when~~ while part of an atom.

- Similarly, nucleons (protons + nuetrons) can be thought to occupy energy levels within the nucleus.

- This is known as the Shell Model of the nucleus.

- Just like the electrons, if energy is given to the nucleus, it may be raised to an excited state. When it returns to the lower energy state, it will give off energy equal to the energy difference between the two nuclear energy states.

Nuclear Bin

Radioactivity

- Discovered by Henri Becquerel in 1896.

~~Radioactivit~~

Radioactivity: a phenomenon in which radiation is given off by the nucleus. This radiation may be in the form of electromagnetic radiation, particles or both.

- Most "heavy" nuclei ($Z > 82$) are unstable.

"Unstable" means that the nucleons (protons + neutrons) have excess energy and the nucleus is not in the lowest energy state.

The nucleus attempts to 'shed' the excess energy and return to the lowest energy state.

Modes of Radioactive Decay:

1) Alpha particle decay (α)
2) Beta-minus decay (β^-)
3) Beta+plus decay (β^+)
4) Electron Capture (E.C.)
5) Gamma Emission (γ)
6) Internal Conversion

① Alpha particle decay (α)

- an ~~α~~-particle is a Helium nucleus $^{4}_{2}He$

2 protons, 2 neutrons, +2 charge

- As the number of nucleons increase ~~beyond~~ ($z>82$) α-decay happens most frequently.

Alpha decay:

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

↑ daughter ↑ α-particle ↖ disintegration energy

disintegration energy - difference between the mass of the original nucleus and the daughter products.

e.g.: $^{226}_{88}Ra \longrightarrow \, ^{222}_{86}Rn + \, ^{4}_{2}He + 4.87\,MeV$

a) Mass is reduced by 4 (A)
b) proton number reduced by 2 (Z)

- Alpha particles emitted by a specific nuclide will have the same discrete energies.

② Beta-minus decay (β^-)

- a β-particle is an electron, either positive or negative.

- In β^- decay an electron (β^-) is ejected from the nucleus.
- The β^- particle doesn't exist in the nucleus, but is created by the conversion of a neutron to a proton. ${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + \bar{\nu}$

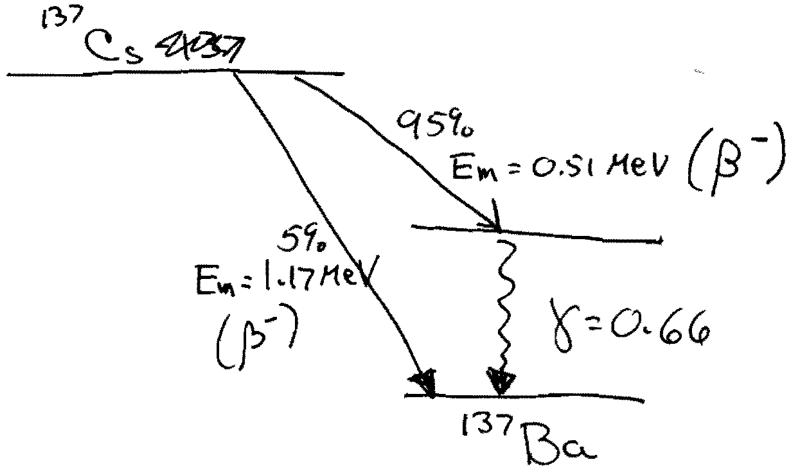
$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \bar{\nu} + Q $$

a) Total Mass remains same (A)
b) proton number increases by 1 (Z)

e.g. - ${}^{32}_{15}P \longrightarrow {}^{32}_{16}S + {}^{0}_{-1}\beta + \bar{\nu} + 1.7\ MeV$

${}^{137}_{55}Cs \longrightarrow {}^{137}_{56}Ba + {}^{0}_{-1}\beta + \bar{\nu} + 0.66\ MeV$

- Beta particles are emitted with a range of energies; from ϕ up to the maximum Q.



(3) Beta-plus decay (β^+)

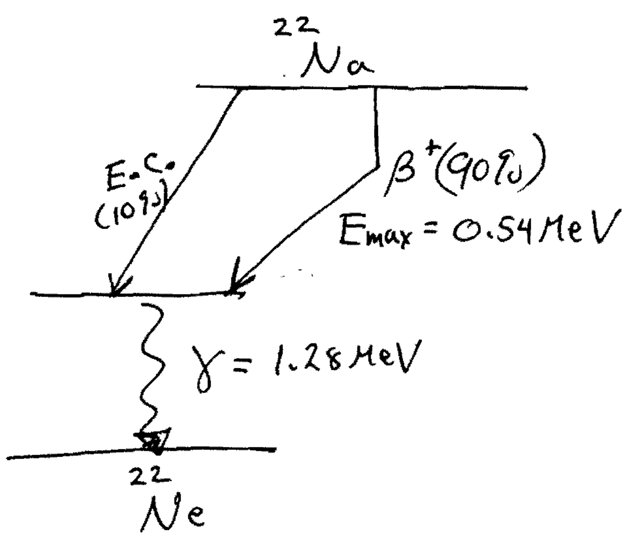
- in β^+ decay, a <u>positron</u> is ejected from the nucleus by the conversion of a proton to a neutron:

$$ {}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}\beta + {}^{0}_{0}\nu $$

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{1}\beta + {}^{0}_{0}\nu + Q $$

a) Total mass remains same (A)
b) proton number decreases by 1 (Z)

e.g.: $ {}^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + {}^{0}_{1}\beta + {}^{0}_{0}\nu + 1.82\ MeV $



(4) Electron Capture

In electron capture, one of the orbiting electrons is captured by the nucleus and transforms a proton to a neutron:

$$^{1}_{1}p + ^{0}_{-1}e \rightarrow ^{1}_{0}n + \nu$$

In general:

$$^{A}_{Z}X + ^{0}_{-1}e \rightarrow ^{A}_{Z-1}Y + \nu + Q$$

electron capture is an alternative process to Positron decay. (both convert $p \rightarrow N$)

electron Capture interacts primarily with K-shell electrons due to the proximity (K-capture)

Electron 'hole' is then filled giving rise to Characteristic X-Rays.

(5) Gamma Emission:

During radioactive decay, the daughter nucleus is formed in an unstable ~~energy~~ energy state.
When the nucleus goes from the excited state to the ground state, electromagnetic radiation is emitted.
These are known as gamma (γ) rays.

(6) Internal Conversion

Here, the excess energy of the excited nucleus is passed on to one of the orbital electrons which is then ejected from the atom.

The kinetic energy of the electron is equal to the energy released by the nucleus minus the binding Energy of the electron.

Transition Energy: Total energy released during the radioactive decay of a nucleus. (also known as disintegration energy)

Auger Electron: an electron ejected from an orbital shell by the energy released in an energy level transition.
Electron is usually from the same orbit as the cascading electron.

Fission: The splitting of an atomic nucleus; ~~usually~~ by bombarding the nucleus with neutrons, making it unstable

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + Q$$

The energy released (Q) is the difference between the mass of the parent and the masses of the daughter products.
The additional neutrons may go on to react with other $^{235}_{92}U$ nuclei, causing a chain reaction.

Fusion: Two low mass nuclei are combined to produce one nucleus

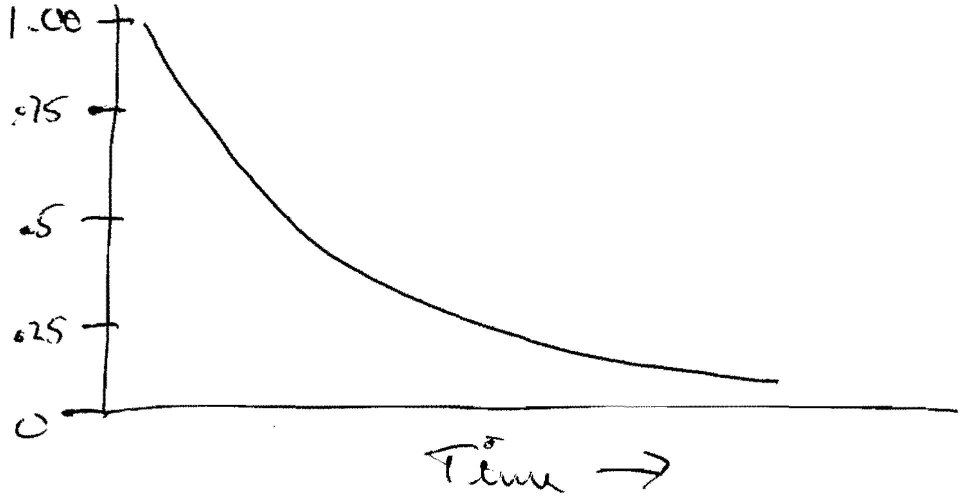
$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + Q$$

Q is released since the mass of the daughter products is less than the parent products.

Radioactive Decay:

- As radioactive materials ~~give off particulate~~ decay the number of gamma and particulate radiations decrease.

If we plot the number of emissions detected over time, we get a plot like:



This plot can be represented by the equation

$$A = A_0 e^{-\lambda t}$$

where,

A - activity at time "t"
A_0 - initial activity of isotope
λ - decay constant
t - time

- Activity ~~mea~~ is a measure of the number of radiations coming from the atom.
It is measured in disintegrations per second (dps)

Mean life : (Average life)

$$T_{Ave} \cong \frac{T_{1/2}}{0.693} = 1.44\, T_{1/2}$$