Nuclear Chemistry

What are Nuclide?

A particular type of nucleus which is characterized by specific atomic number and nucleon numbers.

Mass number = Number of protons + number of neutrons

Mass number

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

Atomic Symbol

Atomic number

Periodicity in Nuclear Properties: The Magic Numbers

- Similar to the periodic variations in the properties of elements with the number of electrons in the atoms, as 2, 10, 18, 36,54 and 86 for the classification of elements, there is analogy in the nuclear properties that vary periodically.
- The period comes to an end when the number of protons or neutrons in nucleus is equal to 2, 8, 20, 50, 82 or 126 referred as Magic numbers.
- The variations in properties can be discussed as further.

1. Tendency of Pairing

- Nucleons form pair up to form a stable bonds similar to that of electrons (neutrons form pair with neutrons and protons form pair with the protons).
- Even-Z, even-N nuclides are the most abundant amongst stable nuclides in nature:165 out of 274.
- The (n+n); (p+p); (n+p) rule for the formation of stable nuclides from ^{16}O to ^{35}Cl is another evidence for this.

- According to this rule all odd-Z elements have only one while even-Z elements have three stable isotopes over this region.
- The heaviest stable nuclide in nature is ^{209}Bi with 126 neutrons.
- The stable end product of naturally occurring radioactive series of elements is Pb with 82 protons, while for man made is ^{209}Bi with 126 neutrons.

2. High Mean Binding Energy

- The maxima occur in a plot of mean Binding energy as a function of A, at the magic numbers of Z or N.
- The Z and N are magic numbers and in ^{4}He, ^{40}Ca, ^{208}Pb, ^{16}O, the binding energy per nucleon is very high.

3. Abundance in Nature

- The abundantly occurring nuclide are those with magic numbers of protons or neutrons or both. Oxygen (n+p=16) is one such examples.
- The large fluctuations up-to ^{19}F are attributed to the preferential use up in the subsequent thermonuclear reactions.

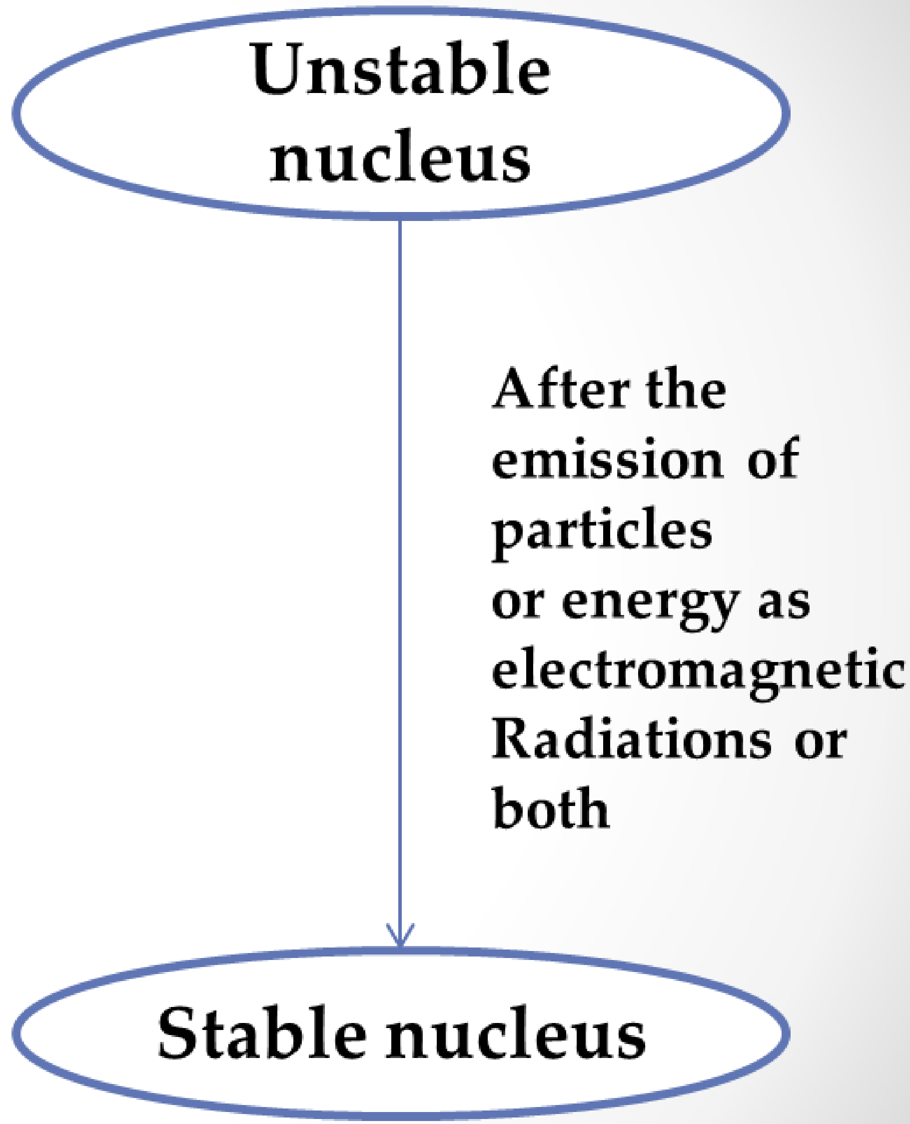
4. Number of Stable isotopes and Isotones

- The number of isotopes of a given element (Z constant) which are stable is a reflection of the relative stability of that element. If this number is plotted as a function of Z, distinct peak occurs at Z=20 (Ca), 50 (Sn) and 82 (Pb) compared with their immediate neighbours of Z value ± 1 of the above values, similarly for the isotones where the number of neutrons are constant.

Radioactive decay

- Number of protons and neutrons is fixed in a nucleus which is either stable or unstable, depending on several factors.
- Atoms having an equal number of protons and neutrons or not having too large a number of protons and neutrons together are much stable.
- Very large nuclei are unstable even if they contain equal numbers of neutrons and protons.

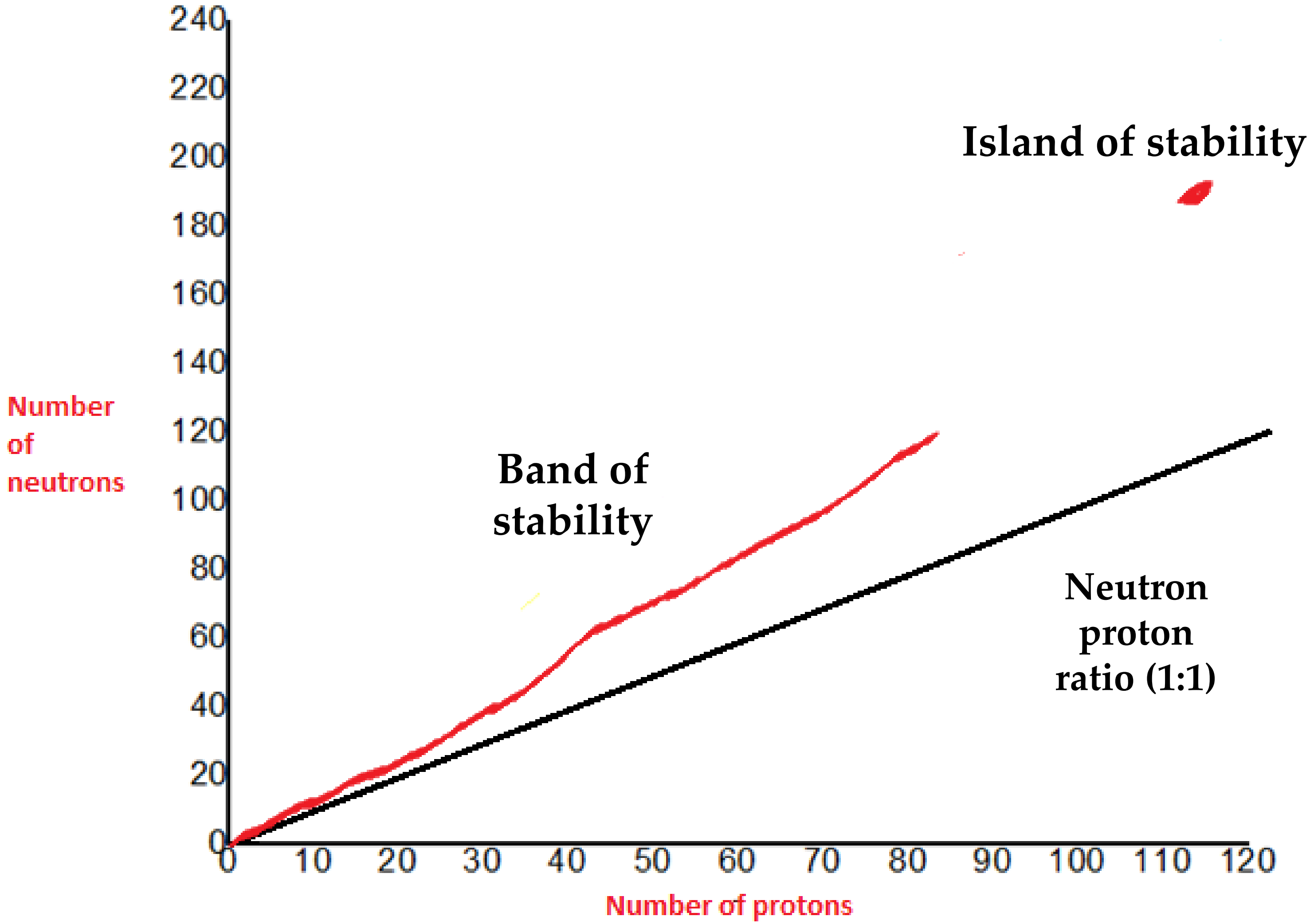
- Atoms with unstable nuclei are radioactive and are labeled as radionuclide.
- Unstable atoms undergo a process called radioactive deacy to reach a more stable state.



- **Half-life**: It is defined as the time required by one-half of the radioactive isotope to decay. It may range from 10^9 years to 9 seconds.
- The product of a radioactive decay process is called **daughter** of the parent isotope.
- The daughter isotope may itself be unstable, which will keep on decaying until it reaches a stable state.

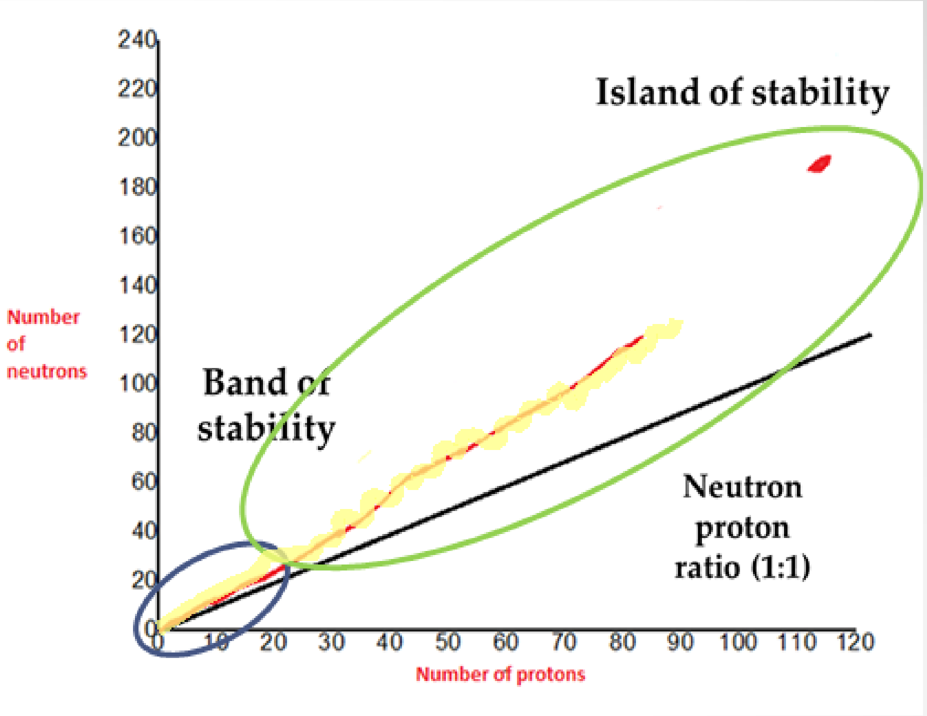
Neutron-Proton Ratio

- The ratio between number of neutrons and protons in the nucleus of an atom is called n/p ratio.
- An element having more than proton in the nucleus of an atom will experience a repulsive force between the like charges.
- Neutrons helps in stabilizing the nucleus and neutron/proton ratio helps in determining that stability.



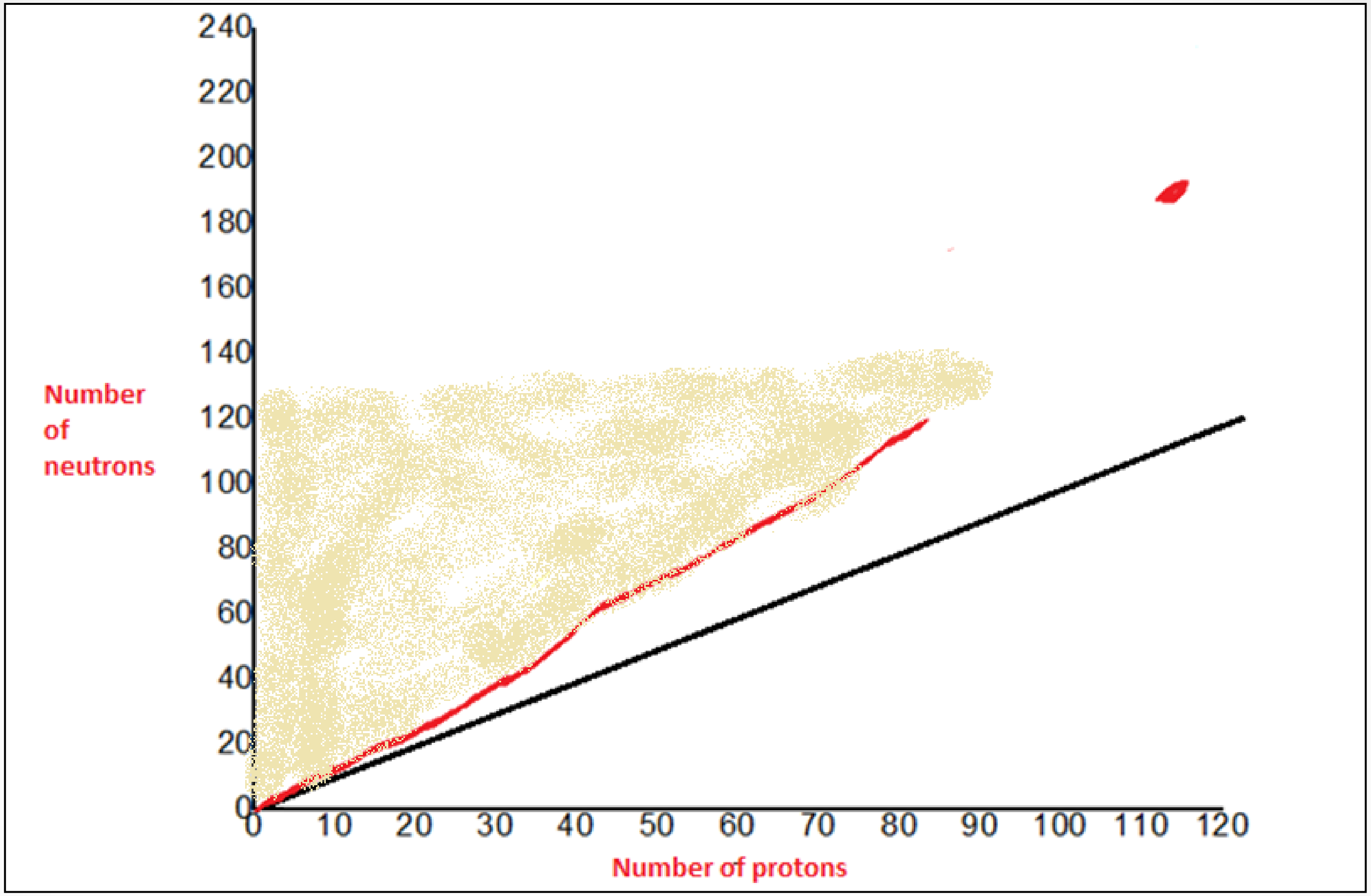
Island of stability
Band of stability
Neutron proton ratio (1:1)
Number of neutrons
Number of protons
240
220
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120

For smaller Nuclei ($Z \leq 20$) the n/p ratio is nearly equal to 1:1 and the nucleus is considerably stable (shown by blue circle)



As the size of the nucleus increases more number of neutrons are required to stabilize the nucleus. (shown by green circle)

Yellow shaded regions show that what nuclides would be stable and the range is known as band of stability of nucleus.



The shaded region above the band of stability refers to nucleus having too many protons and hence the nucleus becomes stable after the β- emission

Types of Radioactive decay

- α-decay : Loss of an α-particle (He atom)

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He$$

- β-decay: Loss of β-particle (high energy electron)

$$^{131}_{52}I \rightarrow \, ^{134}_{54}Xe + \, ^{0}_{-1}e \;\; (^{0}_{-1}\beta)$$

- Positron Emission
- Gamma Emission
- Electron K-capture