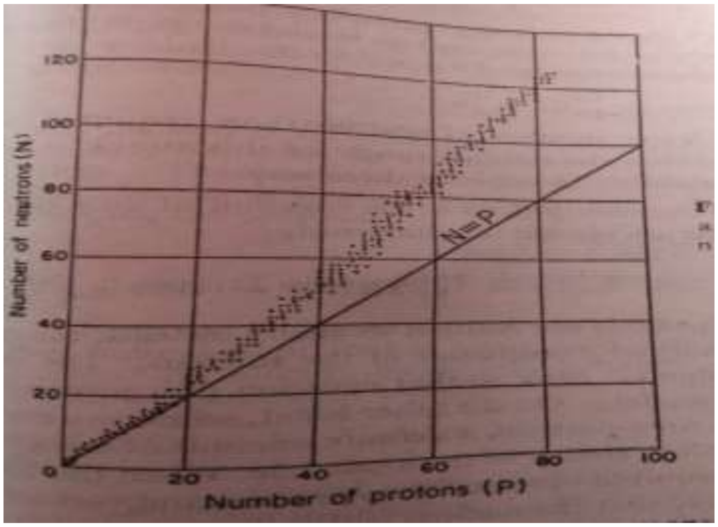
Nuclear Stability: The stability of nucleus may be explain on the basis of n/p ratio, Oddo-Harkins' even-odd rules, packing fraction as well as on the basis of mass defect and nuclear binding energy.

Nuclear Stability and n/p ratio (J.D.Lee, RPS, AKD)

The stability of a nucleus depends on the number of protons and neutrons present in that nucleus. For elements of low atomic number (up to atomic number 20 i.e. Ca) the most stable nuclei exist when the nucleus contains an equal number of proton (p) and neutron (n). This means that the ratio n/p = 1. Elements with higher atomic number are more stable if they have a slight excess of neutrons, as this increases the attractive force and also reduces repulsion between positively charge protons. Thus the n/p ratio increases progressively up to about 1.6 at atomic number (Z) 92 (Uranium). In elements with still higher atomic number, the nuclei have become so large; they undergo spontaneous disintegration (fission). These trends may be shown graphically, plotting neutron number against atomic number (Z) and n/p ratio against atomic number (Z). It is found that in many cases, there exist several stable isotopes for a particular value of Z. This is why we get a stability zone which widens for higher Z values rather than a sharp line.



It is found that, the nucleus becomes unstable when n/p ratio lying outside of the ‘stability region’ of that nucleus, it can be clear from Segre chart (i.e. n/p ratio vs z curve).The unstable nucleus disintegrate and form a stable nucleus of a new element in the following manner:

(I) When n/p ratio lying above the ‘stability region’: n/p ratio lying above the stability zone that means the number of neutron in that nucleus is higher than that of number of neutron required for stability of that nucleus. Such unstable nucleus gains their stability by decreasing number of neutron through β^- emission or by neutron emission which is depicted below:

(i) Beta-emission: The nucleus with high n/p ratio may adjust to stable nucleus by converting a neutron into a proton, and there by a β^- particle is emitted from the nucleus.

$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e\ (\beta^-) + {}^{0}_{0}v^-$ (antineutrino)

Example: (a) $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + {}^{0}_{0}v^-$ (antineutrino)

(b) $^{24}_{11}Na \rightarrow {}^{24}_{12}Mg + {}^{0}_{-1}e + {}^{0}_{0}v^-$ (antineutrino) (c) $^{133}_{53}I \rightarrow {}^{133}_{54}Xe + {}^{0}_{-1}e + {}^{0}_{0}v^-$

(d) $^{141}_{56}Ba \rightarrow {}^{141}_{57}La + {}^{0}_{-1}e + {}^{0}_{0}v^- \rightarrow {}^{141}_{58}Ce + {}^{0}_{-1}e + {}^{0}_{0}v^- \rightarrow {}^{141}_{59}Pr + {}^{0}_{-1}e + {}^{0}_{0}v^-$

In the last example, there is a series of β^- decays to produce the product nuclides progressively stabler with the gradual decrease in the n/p ratio.

(ii) Neutron-emission: An obvious way to decrease high n/p ratio is the emission of neutrons from the nucleus. Though the neutron does not have any Coulombic potential barrier, due to its appreciably high nuclear binding energy (8MeV), the neutron emission tacks place only in highly energetic nuclides.

Example: $^{87}_{36}Kr \rightarrow {}^{87}_{36}Kr + {}^{1}_{0}n$

(II) When n/p ratio lying below the 'stability region': When n/p ratio lies below the stability region, it may have different possible ways to decays to increase the n/p ratio.

(i) Positron emission: Positrons are actually positive electrons and it leads to β^+ - radiation along with a neutrino (${}^{0}_{0}v$) due to the transformation of a proton into a neutron and thus low n/p ratio is adjusted to a stable nucleus.

${}^{1}_{+1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + {}^{0}_{0}v$ (neutrino)

It was found that the amount of energy required for a positron emission from the nucleus is ($\geq$ 1.20 MeV). Hence, it occurs generally in relatively higher energetic nuclides.

Example: (a) ${}^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{+1}e + {}^{0}_{0}v$ (neutrino) (b) ${}^{19}_{10}Ne \rightarrow {}^{19}_{9}F + {}^{0}_{+1}e + {}^{0}_{0}v$

(c) ${}^{13}_{7}N \rightarrow {}^{13}_{6}C + {}^{0}_{+1}e + {}^{0}_{0}v$ (d) ${}^{30}_{15}P \rightarrow {}^{30}_{14}Si + {}^{0}_{+1}e + {}^{0}_{0}v$ (d) ${}^{12}_{153}I \rightarrow {}^{121}_{52}Te + {}^{0}_{+1}e + {}^{0}_{0}v$

(ii) K- Electron capture: When sufficient energy ($\geq$ 1.20 MeV) for the positron emission is not available, the nucleus may capture an electron from nearest K-Shell and converted a proton into a neutron and thereby adjusted low n/p ratio to a stable nucleus. This phenomenon is known as K-electron capture process which is characterized by X-Ray analysis.

${}^{1}_{+1}p + {}^{0}_{-1}e$ (K-electron capture) $\rightarrow {}^{1}_{0}n + {}^{0}_{0}v$ (neutrino)

Example:

(a) ${}^{40}_{19}K + {}_{-1}e$ (K-electron capture) $\rightarrow {}^{40}_{18}Ar + {}^{0}_{0}v$ (b) ${}^{7}_{4}Be + {}_{-1}e$ (K-electron capture) $\rightarrow {}^{7}_{3}Li$

(c) ${}^{55}_{26}Fe + {}_{-1}e$ (K-electron capture $\rightarrow {}^{55}_{25}Mn$ (d) ${}^{37}_{18}Ar + {}_{-1}e$ (K-electron capture) $\rightarrow {}^{37}_{17}Cl$

(e) ${}^{48}_{23}V + {}_{-1}e$ (K-electron capture) $\rightarrow {}^{48}_{22}Ti$ (f) ${}^{54}_{25}Mn + {}_{-1}e \rightarrow {}^{54}_{24}Cr + + {}^{0}_{0}v$

(iii) Alpha-emission: α- particle emission also leads to the increase of the n/p ratio. It generally occurs for the heavy nuclides.

Example: $^{238}_{92}U$ (n/p = 1.58, unstable in this region) → $^{234}_{92}Th$ (n/p = 1.60) + $^{4}_{2}He$

(iv) Proton-emission: Proton emission can also increase the n/p ratio, but in the proton emission, it will require an additional amount of energy to cross the Coulombic potential barrier. Hence, this mode of decay occurs for the nuclides of very much high energy.

Nuclear Stability and Even-Odd Nature of the Nucleons (Harkin,s –Oddo Rule):

The nuclei having even number of neutrons and protons are the most stable and most abundant ones in the Earth's crust. It was found that there are 162 numbers of stable isotopes in the Earth's crust where even number of proton and even number of neutron were present and it is about 85% of that of Earth's crust.

For details of this study follow a text book. (Ref.AKD)

Nuclear Stability and Packing Fraction: The packing fraction (f) for each nuclide has introduced to compare their mass deviation and consequently their nuclear stability.

It is defined as follows: Packing fraction (f) = $\frac{Actual\ isotopic\ mass - Mass\ number}{Mass\ number}$x 10^4

Packing fraction may be negative, positive or zero. More the negative value of packing fraction signifies more stable is the nucleus.

For details study consult text book. (Ref.AKD)