Atomic nucleus

- Stability of the nucleus:

To determine the stability of the nucleus, we are interested in studying binding energy per nucleon.

Binding energy per nucleon: $E_b/_{nucleon}$

Is the minimum energy needed to extract a nucleon from the nucleus.

$$E_b/_{nucleon} = \frac{E_b}{A}$$

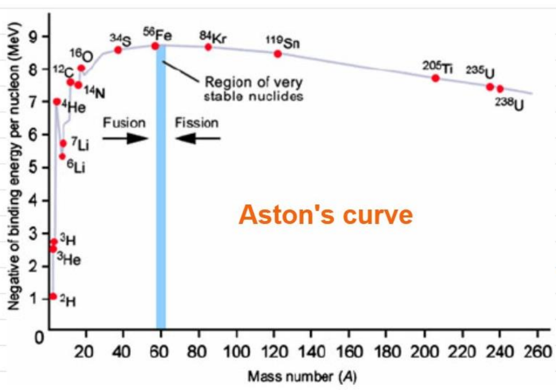
Higher $E_b/_{nucleon} \Longrightarrow$ More stable

The Nickel ($^{62}_{28}Ni$) and Iron ($^{56}_{26}Fe$) have the highest $E_b/_{nucleon}$ (around 8.8 Mev per nucleon)

Table of the binding energy per nucleon (researchgate)

Nucleus	Z	A	B/A (our model, MeV)
H	1	3	3.29123
He	2	4	7.40526
Li	3	6	4.93684
Li	3	7	4.54503
Be	4	9	5.75965
B	5	10	6.91158
B	5	11	6.52262
C	6	12	7.40526
C	6	13	7.0466
N	7	14	7.75789
N	7	15	7.42877
O	8	16	8.02237
O	8	17	7.71987
F	9	19	7.94899
Ne	10	21	8.13404
Na	11	23	8.28661
Mg	12	25	8.41457
Mg	12	26	8.18587
Al	13	27	8.52344
Si	14	29	8.61718
Si	14	30	8.41614
P	15	31	8.69875
S	16	34	8.59107
Cl	17	37	8.49231
Ar	18	38	8.72849
K	19	41	8.63155
Ca	20	43	8.69114
Sc	21	45	8.74526
Ti	22	47	8.79465
Ti	22	48	8.65817
V[a]	23	50	8.70888
Cr	24	52	8.75551
Mn	25	55	8.67687
Fe	26	56	8.83839
Fe	26	57	8.72109
Co	27	59	8.76215
Ni	28	61	8.80037
Cu	29	63	8.83606
Cu	29	65	8.62354
Zn	30	66	8.76663
Ga	31	69	8.70121
Ge	32	70	8.83342
As	33	75	8.58113
Se	34	76	8.70953
Br	35	79	8.65242
Kr	36	80	8.77204

Nuclear binding energy per nucleon



The binding energy per nucleon as function of the number of nucleons

For $1 \leq A \leq 20$: $E_b/_{nucleon} < 8$ Mev

For $20 < A < 190$: $E_b/_{nucleon} > 8$ Mev

For $A \geq 190$, $E_b/_{nucleon} < 8$ Mev

Nuclei having a mass number (A) between 20 and 190, have higher stability. ($E_b/_{nucleon} > 8$ Mev)

- Nuclear strong force (stronginteraction)

* The nuclear force, is an interaction between nucleons(protons and neutrons) other than electric and gravitational. It's 100 times greater than electric force.

* It's a very short range (to 3 fm) force, which acts to hold neutrons and protons together in nuclei. In nuclei, this force acts against the enormous repulsive electromagnetic force of the protons.

* In the nucleus, protons encounter repulsive electric forces; so one can ask how the nucleus doesn't get explode. As the nuclear force is attractive in a range from 1 to 3 fm, it dominates over the electric repulsive force, assuring stability of the nucleus.

Stability of the nucleus:

The stability of the nucleus is defined through two factors:

- neutron to proton ratio: Presence of neutrons reduces the electric repulsion of the nucleus. For nuclides with Z less than or equal 20, we have almost Z=N; with Z greater than 20, we have N>Z. We are interested in studying neutron to proton ratio.

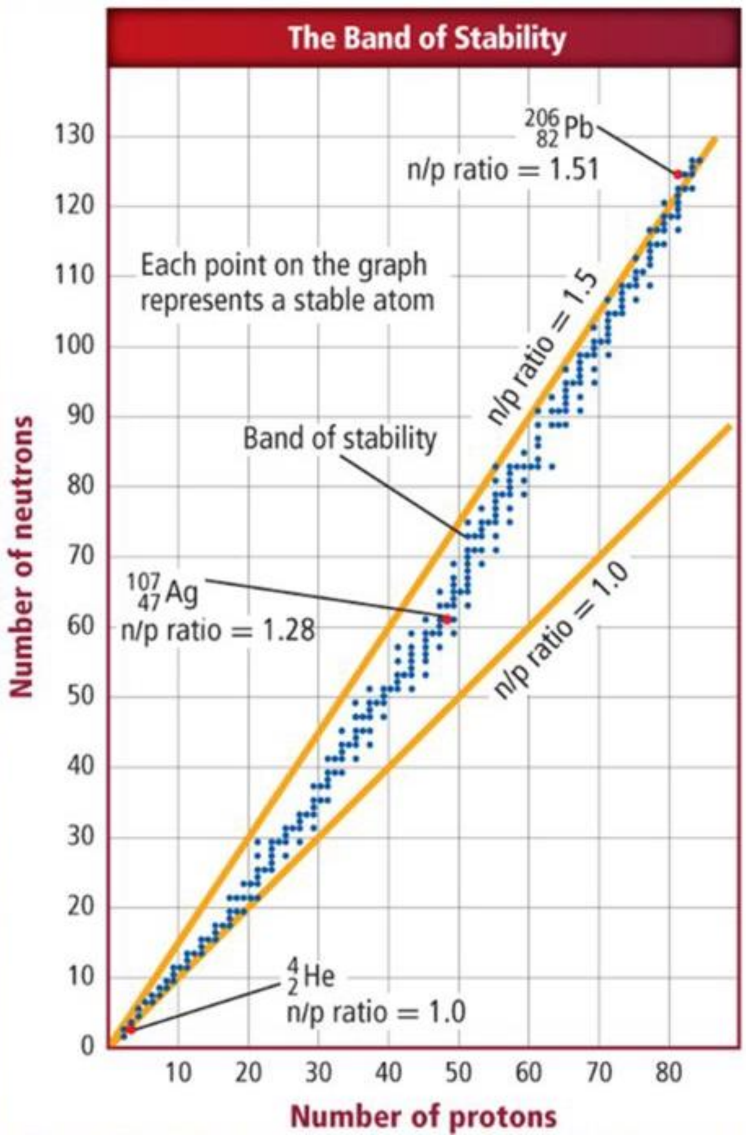
- number of nucleons: The presence of extra protons, reduces the stability of the nucleus; in general, we don't have stable nucleus with Z>82. (Pb:lead).
Also the presence of extra number of neutrons makes it difficult to have stable nucleus; a large nucleus with enormous neutrons increases the spacing between protons thus reducing the nuclear force;in this case the repulsive electric force dominates.

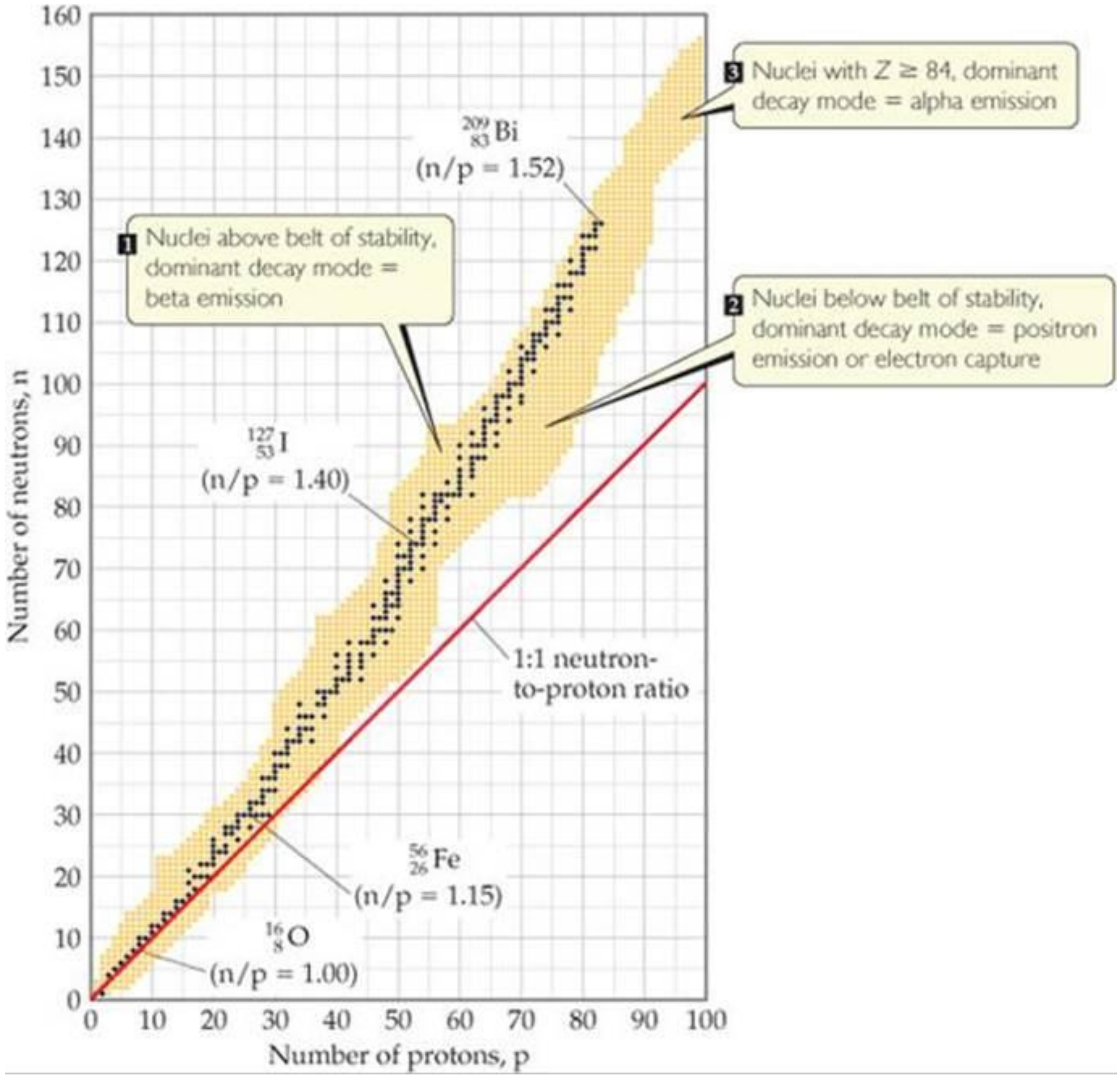
Reasons of instability:

* too many protons.

* too many neutrons.

*too many of both.


The Band of Stability
Number of neutrons
Number of protons
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
206 82 Pb
n/p ratio = 1.51
Each point on the graph represents a stable atom
n/p ratio = 1.5
Band of stability
107 47 Ag
n/p ratio = 1.28
n/p ratio = 1.0
4 2 He
n/p ratio = 1.0



Nuclei with $Z \geq 84$, dominant decay mode = alpha emission
$^{209}_{83}Bi$ (n/p = 1.52)
Nuclei above belt of stability, dominant decay mode = beta emission
Nuclei below belt of stability, dominant decay mode = positron emission or electron capture
$^{127}_{53}I$ (n/p = 1.40)
1:1 neutron-to-proton ratio
$^{56}_{26}Fe$ (n/p = 1.15)
$^{16}_{8}O$ (n/p = 1.00)
Number of neutrons, n
Number of protons, p