Instability of heavy elements - beyond Lead Pb

Ronen Yavor Sep. 05, 2023

Abstract

This paper examines the hypothesis that the stability of heavy nuclei, beyond Lead (Pb_{82}) depends on the energy balance of a proton inside it, meaning the difference between the binding energy and the electric energy of the center proton.
The value of the maximum electric energy of the center proton is calculated for all heavy nuclei and compared with the number of nuclear bonds, that is required to keep the proton stable and so the nucleus as a whole.

The research results are the following:

- from about Lead (Pb_{82}) and till about Dubnium (Db_{105}) six nuclear bonds are required to keep the center protons stable; with some certain probability one nuclear bond could break for a certain amount of time, leading to instability and radioactivity occurs. The half-life (or the probability that the radioactive decay occurs) depends on various factors, such as the general form of the nucleus, the number of excess neutrons it possesses and its symmetry.
- beyond Dubnium (Db_{105}) more than six nuclear bonds are required to keep the center protons stable and therefore these nuclei are constantly unstable and have as a result a short half-life.

According to the model assumption the energy of one bond shall be radiated, so the expected value for the emitted particle is about 1-2 times e_b (with $e_b \approx 5.7\ MeV$ the bonding energy of a single nucleon bond in the nucleus [13]), meaning an emission in the range of about 5-12 MeV (depending on if one or two bonds were opened).

These results are not new, but their explanation with the help of illustration and calculation is another reinforcement for the model.

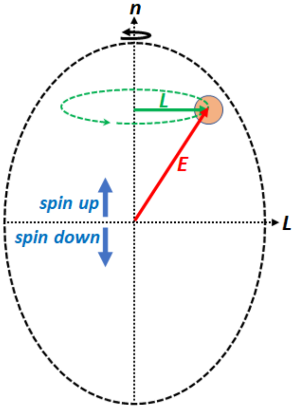
Content

The model at a glance

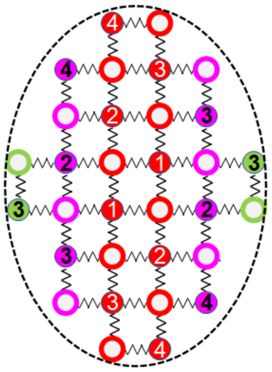
A brief description of the model [13]:

- The nucleus has an ellipsoid shape.
- The nucleons are connected in a cubic form.
- Protons are connected to neutrons (**p-n**).
- Neutrons are connected mainly to protons.
- The protons are populated and organized in shells in the nucleus in a full analogy to those of the electrons in the atom.
- The energy layers (principal quantum number **n**) grow along the **z**-axis of the nucleus in its both directions (more precisely **n** grows with its distance from the origin).
- The perpendicular distance from the **z**-axis in the **x-y**-plane reflects the angular momentum (**L**) and so the orbitals.
- The upper half of the ellipsoid is referred to as spin-up and the lower part as spin-down.
- The nucleus possibly rotates around its **z**-axis.

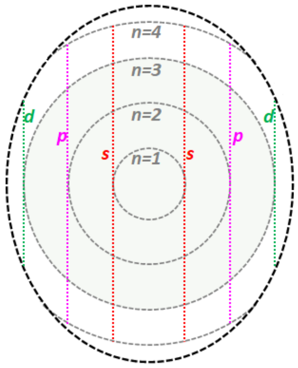
The following drawings describe the idea via cross sections in the **x-z**-plane of the nucleus.



1: a nucleon in the nucleus



2: the bonds between the nucleons



3: the energy levels of the nucleus

1. One nucleon (circle) is observed inside the ellipsoid (dashed line) that encloses the nucleons and schematically defines the nucleus surface:
    - the distance from the origin represents its energy **E**.
    - the distance from the **z**-axis depicts it angular momentum **L**.
    - the nucleons in the upper half have spin up, and in the lower one spin down.
2. The bonds between the nucleons are shown for visibility as springs.
    - **Protons**: full circles of the **s**, **p** and **d** sub-orbitals. **Neutrons**: hollow circles.
3. The circles of equal energy states **n** in the ellipsoid.
    - the lines mark the development of the **s**, **p** and **d** sub-orbitals along the **z**-axis.
    - the **s** line crosses all **n** circles from 1 to 4 (**s1** to **s4**).
    - the **p** line begins by **n**=2 and reaches till **n**=4 (**p2** to **p4**).
    - the **d** line begins by **n**=3 and reaches the ellipsoid border, before it reaches the **n**=4 circle, and therefore there are no **d4** states at this stage (only **d3**).

Introduction

Our former paper in this series dealt with the instability of nuclei due to the lack or excess of neutrons. [13]
In this research we discuss the instability of heavy nuclei.
The instability is divided in two:

- Radioactivity, which is the subject of this paper.
- Nuclear fission, which will be discussed in the following paper.

The model assumption is that the basic mechanism for both phenomena is the same, but for fission additional requirements must be fulfilled.

The radioactivity hypothesis

In heavy nuclei, the electrical energy of the central protons determines whether the nucleus is unstable.
The mechanism that is assumed, according to the model, to determine instability of heavy nuclei, beyond Lead (Pb), is the electric energy, that overcomes the binding energy (of the strong nuclear force) between the nucleons.
The instability occurs in the middle of the ellipsoid, where the electric energy reaches its maximum value; when we get to the nuclear fission, this idea will be further discussed and strengthen.

The calculations according to the model deliver a rough prediction to the nucleus stability. We find that for nuclei larger than about Lead (Pb_{82}) and till about Rutherfordium (Rf_{104}) six nuclear bonds are required to keep the center protons stable.

The model hypothesis is that due to movements or fluctuations within the nucleus there is a certain probability that these six bonds are temporarily reduced to five bonds every certain timespan; as a result the center proton becomes unstable, possibly ending with a radioactive emission; after several steps of this type the nucleus is transformed to (Pb_{82}) where five bonds are sufficient to keep the center protons stable and radioactivity ends.

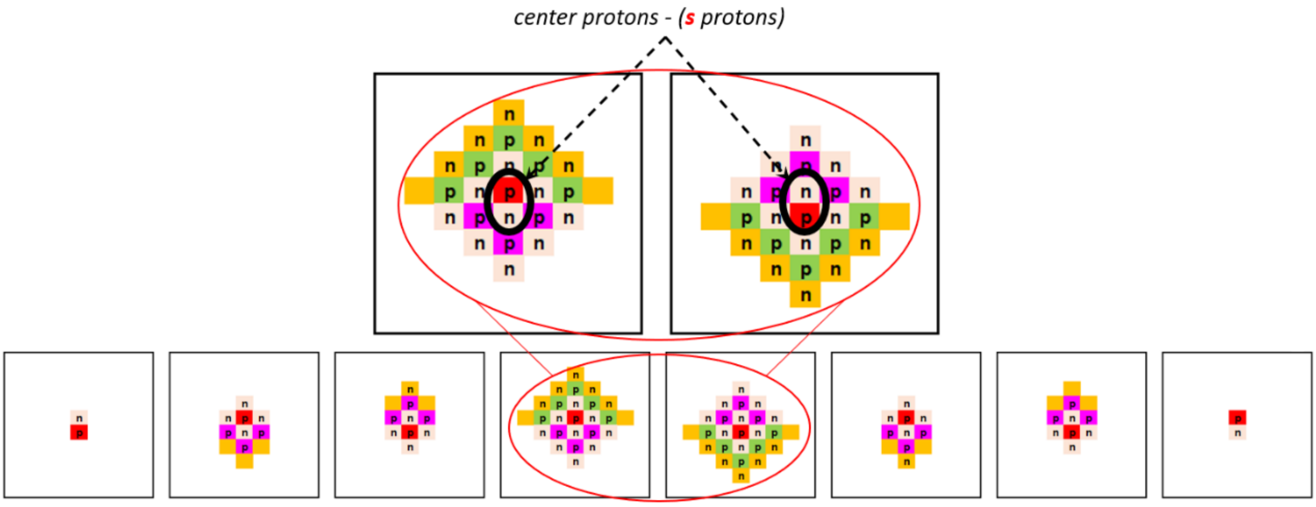
For nuclei beyond Rutherfordium (Rf_{104}) even the maximum number of potential nuclear bonds which is six, is not enough to keep the center protons stable and therefore these nuclei have a short half-life.

The research

The radioactivity of heavy nuclei

We make the following definition:
The two centers (or center protons) of the nucleus: the two **s** sub-orbital protons in the middle of the nucleus; there are two central layers in the middle of the nucleus; one at the positive side of the **z**-axis (spin-up side) and the other at its negative (spin-down side); therefore there are also two centers.

As an example the centers of the Kr_{36}^{84} nucleus are shown.



The two centers of the Kr_{36}^{84} *nucleus; the nucleus and zoom in on its center layers.*

The center protons have the largest electric energy in the nucleus.
Next we calculate this energy for the heavy nuclei and compare it with the number of bonds (of the strong nuclear force) that are required in order to stabilize these protons (to compensate the electric energy).

Maximum electric energy as a function of the number of nuclear bonds

The binding energy of the proton ***x*** in the nucleus is: $E_{\boldsymbol{b}_x} = e_{\boldsymbol{b}} \cdot n_{\boldsymbol{b}_x}$ [13] where:

- $n_{\boldsymbol{b}_x}$ is the number of nucleon-nucleon bonds of the proton ***x*** in the nucleus.
- $e_{\boldsymbol{b}} = 5.72\ MeV$: the energy of a single nucleon-nucleon bond in the nucleus (assuming they are equal for all bonds in all nuclei).

The electric energy of the proton ***x*** in the nucleus is:

$$E_{\boldsymbol{c}_x} = \frac{e^2}{4\pi\epsilon_0}\frac{1}{d_0}\left\{\sum_{j\neq i}^{Z_x}\frac{1}{d_{i,j}}\right\} = \frac{e^2}{4\pi\epsilon_0}\frac{1}{d_0}\, e_{\boldsymbol{c}_x} \quad \text{with} \quad e_{\boldsymbol{c}_x} \coloneqq \sum_{j\neq i}^{Z_x}\frac{1}{d_{i,j}}$$

- $d_0 = 1.62\ fm$: the minimum distance between two neighboring nucleons in femtometer (assuming all nuclei have the same structure of cubic bonds and distance between their nucleons).
- $d_{i,j}$: the unitless distance between the protons of the indices *i* and *j* measured in multiples of d_0: $d_{i,j} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2}$
- $e_{\boldsymbol{c}_x}$: the unitless relative electric energy of the proton ***x*** in the nucleus (sum of the reciprocal distances).

We analyze the maximum electric energy that a proton can have in dependency on its number of bonds: $(E_{\boldsymbol{b}_{proton_x}} - E_{\boldsymbol{c}_{proton_x}}) \geq 0$ or $(e_{\boldsymbol{b}} \cdot n_{\boldsymbol{b}_{proton_x}} - \frac{e^2}{4\pi\epsilon_0}\frac{1}{d_0}\, e_{\boldsymbol{c}_{proton_x}}) \geq 0$

and get the following table for this equation:

$n_{\boldsymbol{b}_{proton\_x}}$	$e_{\boldsymbol{c}_{proton\_x}}$ max. value	E_b [Joule]	E_c [Joule]	E_b-E_c [Joule]
1	6.43	9.2E-13	9.2E-13	0.00
2	12.87	1.8E-12	1.8E-12	0.00
3	19.30	2.7E-12	2.7E-12	0.00
4	25.73	3.7E-12	3.7E-12	0.00
5	32.16	4.6E-12	4.6E-12	0.00
6	38.60	5.5E-12	5.5E-12	0.00

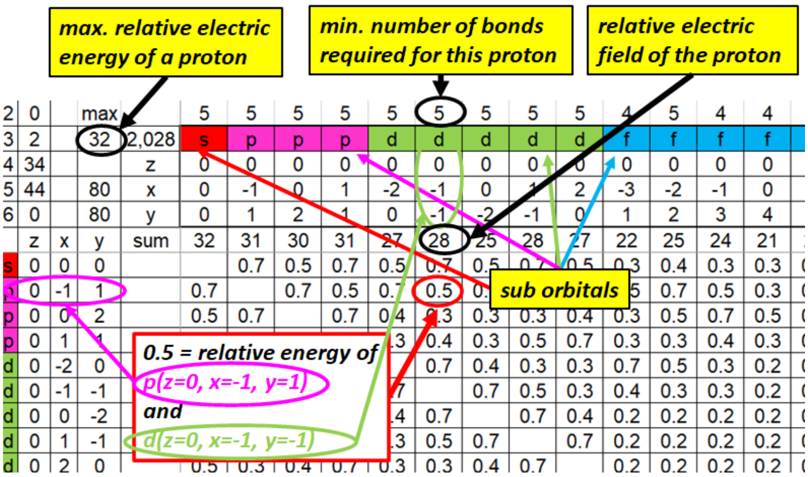
the maximum relative electric energy as a function of the number of nuclear bonds

This means that a proton with a single nuclear bond can sustain, at most, a relative electric energy of 6.43; a proton with two bonds, 12.87 and so on; a proton with 5 nuclear bonds can hold at most a relative electric energy of 38.60.

Calculating the maximum electric energy per proton

We now try to develop the idea of a maximum electric energy at a specific point, that leads a nucleus to a radioactive decay.
We map via Excel files for every single proton in the nucleus how many bonds it has and what is its relative electric energy as shown in the following illustrations (this process is explained also in [13]).

Mapping the relative electric energy of every proton (Hg_{80}^{202})*:*



max. relative electric energy of a proton

min. number of bonds required for this proton

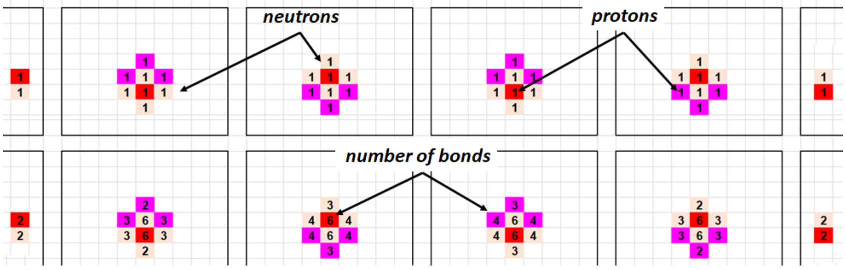
relative electric field of the proton

sub orbitals

0.5 = relative energy of p(z=0, x=-1, y=1) and d(z=0, x=-1, y=-1)

2	0		max		5	5	5	5	5	5	5	5	5	4	5	4	4
3	2		32	2,028	s	p	p	p	d	d	d	d	d	f	f	f	f
4	34			z	0	0	0	0	0	0	0	0	0	0	0	0	0
5	44		80	x	0	-1	0	1	-2	-1	0	1	2	-3	-2	-1	0
6	0		80	y	0	1	2	1	0	-1	-2	-1	0	1	2	3	4
	z	x	y	sum	32	31	30	31	27	28	25	28	27	22	25	24	21
s	0	0	0			0.7	0.5	0.7	0.5	0.7	0.5	0.7	0.5	0.3	0.4	0.3	0.3
p	0	-1	1		0.7		0.7	0.5	[illegible]	0.5	[illegible]	[illegible]	[illegible]	[illegible]	0.7	0.5	0.3
p	0	0	2		0.5	0.7		0.7	0.4	0.3	0.3	0.3	0.4	0.3	0.5	0.7	0.5
p	0	1	1		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.4	0.3	0.5	0.7	0.3	0.3	0.4	0.3
d	0	-2	0		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.7	0.4	0.3	0.3	0.7	0.5	0.3	0.2
d	0	-1	-1		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		0.7	0.5	0.3	0.4	0.3	0.3	0.2
d	0	0	-2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.7		0.7	0.4	0.2	0.2	0.2	0.2
d	0	1	-1		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.5	0.7		0.7	0.2	0.2	0.2	0.2
d	0	2	0		0.5	0.3	0.4	0.7	0.3	0.3	0.4	0.7		0.2	0.2	0.2	0.2

Counting the number of bonds for every proton (Ar_{18}^{36})*:*



We get for every proton:

- Its relative electric energy.
- the number of nuclear bonds it has.
- the minimum number of bonds required for stability.

Results

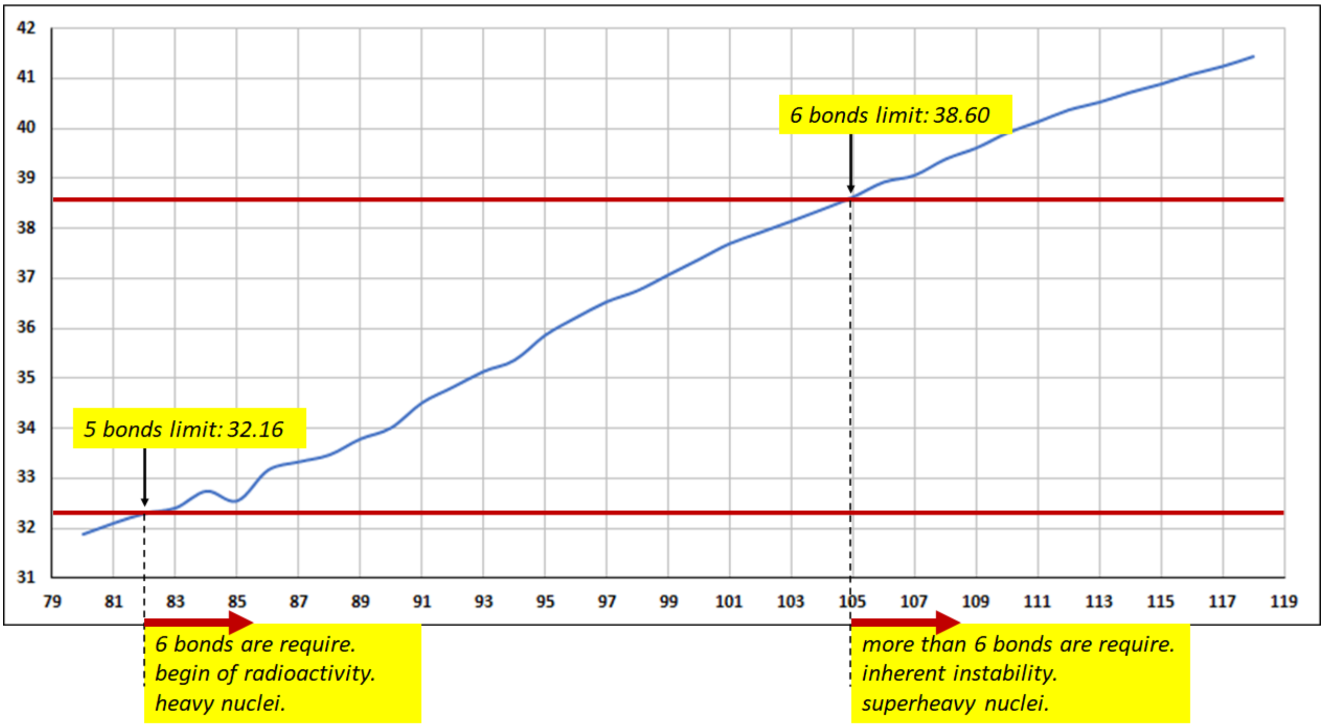
maximum electric field of the heavy nuclei

The following table shows the results of the calculations of the last section. data from [1].

nucleus	Z	max. half-life	bonds	max. e_{c_p}		
Os	76	stable	5	30.61		
Ir	77	stable	5	30.99		
Pt	78	stable	5	31.30		
Au	79	stable	5	31.62	1.7%	deviation from the limit value 32.16
Hg	80	stable	5	31.87	0.9%	
Tl	81	stable	5	32.09	0.2%	
Pb	82	stable	6	32.29		
Bi	83	y	6	32.40		
Po	84	y	6	32.73		
At	85	h	6	32.54		
Rn	86	d	6	33.15		
Fr	87	m	6	33.32		
Ra	88	y	6	33.46		
Ac	89	y	6	33.78		
Th	90	y	6	34.00		
Pa	91	y	6	34.50		
U	92	y	6	34.81		
Np	93	y	6	35.13		
Pu	94	y	6	35.35		
Am	95	y	6	35.85		
Cm	96	y	6	36.21		
Bk	97	y	6	36.52		
Cf	98	y	6	36.75		
Es	99	d	6	37.06		
Fm	100	d	6	37.37		
Md	101	d	6	37.69		
No	102	m	6	37.91	1.8%	deviation from the limit value 38.60
Lr	103	h	6	38.14	1.2%	
Rf	104	m	6	38.37	0.6%	
Db	105	h	6<	38.62	0.1%	
Sg	106	m	6<	38.92		
Bh	107	m	6<	39.06		
Hs	108	m	6<	39.38		
Mt	109	s	6<	39.60		
Ds	110	s	6<	39.90		
Rg	111	s	6<	40.12		
Cn	112	s	6<	40.36		
Nh	113	s	6<	40.52		
Fl	114	s	6<	40.71		
Mc	115	ms	6<	40.88		
Lv	116	ms	6<	41.08		
Ts	117	ms	6<	41.24		
Og	118	ms	6<	41.43		

Results: the number of bonds vs. the relative electric energy

The following graph illustrates the data from the above table.
We see that the radioactivity is expected to begin around Lead (Hg_{80}) and the superheavy nuclei (nuclei that are very unstable with short half-life) are expected to begin around Dubnium (Db_{105}).



6 bonds are require.
begin of radioactivity.
heavy nuclei.

more than 6 bonds are require.
inherent instability.
superheavy nuclei.

Limits of radioactive nuclei (6 nuclear bonds) and superheavy nuclei (beyond 6 bonds)

Discussion of the results and conclusion

The electric energy of the center proton in a heavy nucleus seems to determine its stability. We get that the limit of five nuclear bonds (equivalent to a relative electric energy of 32.16) is, as expected, around Lead (Pb_{86}).

The maximum electric energy of a single proton must therefore not exceed the value of five bonds, because then if one bond is missing, the nucleus will collapse.

This phenomenon occurs in the region between Hg_{80} and Rn_{86} and more precisely around Pb_{82} and could be the explanation to why there are no stable nuclei above it.

The main assumption is that there are changes inside the nucleus and these changes or movements of nucleons and their transform from proton to neutron or vice versa, have a finite number of combinations or states, that the nucleus passes. The character and duration of each of these nucleus states determine its stability.

The total stability of the isotope depends on:

- the probability to reach a five bonds state instead of six.
- the period that this state lasts.
- the chain reaction that is caused by this state.

If more than six bonds are required, approximately from Dubnium (Db_{105}), then the nucleus is unstable inherently and its half-life is dramatically shorten to the range of hours or much less.

According to the model assumption the energy of one bond shall be radiated, so the expected value for the emitted particle is about 1-2 times e_b (with $e_b \approx 5.7\ MeV$ the bonding energy of a single nucleon bond in the nucleus [13]), meaning an emission in the range of about 5-12 MeV (depending on if one or two bonds were opened).

Sources and references

1. *Tables of Nuclear Data: Japan Atomic Energy Agency (JAEA)*
2. *Uranium 235 Fission: Nuclear Power for Everybody (nuclear-power.com)*
3. *Plutonium 239: Nuclear Power for Everybody (nuclear-power.com)*
4. *A Rule for Determining Fissile Isotopes - Yigal Ronen - American Nuclear Society*
5. *Valley of stability - (LibreTexts)*
6. *Neutron emission - (Wikipedia)*
7. *Proton emission - (Wikipedia)*
8. *Transuranium element - (Wikipedia)*
9. *Synthetic element - (Wikipedia)*
10. *Superheavy element - (Wikipedia)*
11. *Radioactive decay - (Wikipedia)*
12. *Alpha particle - (Wikipedia)*
13. *a cubic ellipsoid geometric model of the atomic nucleus and its mass formula - Ronen Yavor - (viXra)*
14. *Nuclear stability depending on the number of excess neutrons - nuclei with closed sub-orbitals - Ronen Yavor - (viXra)*