Re-evaluating Nuclear Binding Energy and Mass Defect:
A Proton-Electron Composite Model Approach

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Abstract

The released energy of exothermic nuclear reactions is usually determined by the difference in mass between source- and target isotope(s). An increase in average binding-energy between source- and target isotope is considered to be the reason a reaction starts. A positive difference between the total target- and total source binding-energy is a good indicator whether the reaction will happen and also for the amount of the released energy – like with α decay reactions. But this does not work for β decay, the numbers for total binding-energy are off by 0.782 MeV. And even worse: the total binding-energy difference can be negative and the average binding-energy per nucleon can go down.

In this paper we will trace this issue back to the decision to consider the neutron to be fundamental at the same level as the proton. The "discovery" of the neutron and how and when it came to be an integral and fundamental part of nuclear physics is an interesting part of history. The question whether or not the neutron is a composite and what its mass is, is directly linked to the question of mass-defect and therefore also the binding-energy of a nucleus. Since ca. 1940 the neutron is considered to be an elementary and fundamental particle on the same level as the proton and the electron. This paper discusses the consequences of this decision for binding-energy/mass-defect and some β-type reactions.

The Structured Atom Model (SAM) does not consider the neutron to be a fundamental particle on the same level as the proton and the electron, but a proton-electron composite, which means a very closely bound system of two particles. This has consequences for the determination of the mass-defect and the equivalence of binding-energy and mass-defect. The effect of this change on some β-type reactions is very illuminating as we will show in this paper.

1 The Issue

During exothermic nuclear reactions the released energy is usually determined by the difference in mass between source- and target isotope(s). An increase in average binding-energy between source- and target isotope is considered to be the reason a reaction starts. A positive difference between the total target- and total source binding-energy is a good indicator whether the reaction will happen and also for the amount of the released energy – like with α decay reactions. But this does not work for β decay, the numbers for total binding-energy are off by 0.782 MeV. And even worse: the total binding-energy difference can be negative and the average binding-energy per nucleon can go down. Take for example the naturally occurring decay of the isotope C-14 to N-14. This β- decay is the basis of the famous radiocarbon dating method introduced by Willard Frank Libby. But if we look at the binding-energy numbers, a strange fact emerges: C-14 has a total binding-energy of 105.284466 MeV per atom and an average binding-energy per nucleon of 7520.319 KeV, while N-14 shows a total value of 104.658596 MeV and an average value of 7475.614 KeV. The total difference is -0.625870 MeV and the average of the target is 44.705 KeV lower. But the decay is clearly happening. Could it be that the binding-energy is not a proper indicator? Can we find a better indicator which not only works in all cases but also gives us the correct reaction energy value?

In this paper we will trace this issue back to the decision to consider the neutron to be fundamental. Is the neutron a fundamental particle on the same level as the proton and the electron or is it a composite of the latter? Scientists have decided this question some 85 years ago in favor of it being fundamental. This decision had consequences for binding-energy as well as mass-defect and it made energetic aspects of beta-decay problematic.

2 History

2.1 The discovery of the neutron

Ernest Rutherford conjectured in 1920 that a neutral particle should exist in the atomic nucleus. This particle could be in his opinion a proton-electron composite, he spoke of a collapsed hydrogen atom. William D. Harkins named this proposed particle a "neutron" in 1921. The first steps to discover the neutron were done by Walther Bothe and Herbert Becker in 1930. They described a strange radiation, which resulted from shooting at beryllium with alpha-particles coming off the radioactive decay of polonium. The radiation was too energetic to be of the gamma type as they initially suspected it to be. They called it beryllium-radiation. In 1931 Irène Joliot-Curie and Frédéric Joliot-Curie continued with experiments about the beryllium-radiation. They assumed something was happening comparable to "compton-scattering". James Chadwick, as a student of Rutherford, initially followed Rutherford's idea of a proton-electron composite and did not believe in the "compton-scattering" proposal. What was seen happening in paraffin had to be an energetic particle. In 1932 he was able to show experimentally, that the beryllium-radiation was not gamma but a fast moving particle, electrically neutral and roughly of the mass of a proton. Chadwick used the name "neutron" again and published his results first in *Nature* [1] and again more extensively in *Proceedings of the Royal Society of London, series A* [2]. This work earned him the Nobel prize in 1935. Also in 1932 Werner Heisenberg published his nucleon-theory [3,4,5]. At the seventh Solvay conference in 1933 titled "Structure & properties of the atomic nucleus" [6] the consensus was more or less, that the neutron had to be an elementary particle instead of a proton-electron composite. The proton-electron composite idea for the neutron was finally dropped in mainstream science around 1940 in favor of assuming the neutron to be an elementary particle.

2.2 The seventh Solvay conference 1933

The conference's main topic was the presentation and discussion of Heisenberg's nucleon theory which was based on the assumption that the nucleus was made up of protons and neutrons without electrons. This assumption would, in his opinion, bring a big simplification to the theory of the atomic nucleus. He considered the neutron to be fundamental, but allowed somehow for the possible disintegration into an electron and a proton. He did this because of the fundamental issues that existed with beta decay and the nitrogen-statistics. Alpha particles were also considered to be part of the nucleus by many attendants. Also Heisenberg applied quantum mechanics theory to the nucleus and was convinced, it was sufficient to explain the nucleus. The discussion afterwards moved between beta decay, neutrinos and the neutron. As an example: Rudolf Peierls [6, 331] asked during the discussion "Why does Mr. Heisenberg conclude that the neutron is really an elementary particle; why not just notice that the neutron never disintegrates into a proton and an electron?"

Be aware, that at this point in time the decay of a neutron into a proton and an electron had not been witnessed yet.

2.3 Determining the mass of the neutron

For Chadwick the mass of the neutron was of utmost importance. He knew from his experiments, the mass was close to the mass of a proton. If the mass of the neutron was less or equal to the sum of mass of a proton and an electron, it could be a proton-electron composite, if it was greater, that was not possible in his opinion. His initial calculations from 1932 pointed into the direction of less mass than the proton, but later work in 1935 together with Maurice Goldhaber showed it to be higher [7]. So he abandoned the idea

of the neutron being a composite. Both also speculated in this paper that the free neutron would be unstable, due to its estimated mass being larger than that of a hydrogen atom. In the following decades, the neutron mass has been determined with even greater accuracy. Greene/Kessler described the process nicely in 1986:

> "The mass difference between the neutron and atomic hydrogen, n - ^{1}H, may be determined from a knowledge of B(d) and existing mass-spectroscopic data on the interval ^{2}H - 2 ^{1}H, […] by the following subtraction:" [8]

B(d) = ^{1}H + n – ^{2}H
B(d) is the binding energy of deuterium = 0.0023886 u (=2.225 MeV)

n = ^{2}H - ^{1}H + B(d)
n = 2.0141017781 u - 1.00782503190 u + 0.0023886 u
n = 1.00866538 u

But also:

n – ^{1}H = 1.00866538 u - 1.00782503190 u = 0.000840348 u = 0.782779963 MeV

The free neutron has 0.000840348 u or 0.782779963 MeV more mass than hydrogen-1 according to the calculation by Greene/Kessler [8]. That value underwent some small changes in the following decades [9], we use 0.782347 MeV in this paper, which is close to currently given values.

2.4 Definitions

Nuclear binding energy (BE) is defined as the minimum energy required to break up a nucleus into its fundamental components (binding-energy with a positive sign). Therefore, this energy (expressed in eV) is released (then with a negative sign) when the nucleus comes together to create structure. Consequently, in theoretical nuclear physics, the nuclear binding energy is considered to be a negative number. In this context it represents the energy of the nucleus relative to the energy of the constituent nucleons when they are infinitely far apart. Both the experimental and theoretical views are equivalent, with slightly different emphasis on what binding-energy means.

Mass-defect (MD) is the difference between the mass of an object (actual mass) and the sum of the masses of its constituent particles (theoretical mass).

The decrease in mass is stated to be equal to the energy given off in the reaction of an atom's creation divided by c^2. This would mean: MD is equivalent to BE [11]. Is this true? What is mass anyway?

> *"**Mass***, in physics, is a quantitative measure of inertia, a fundamental property of all matter. It is, in effect, the resistance that a body of matter offers to a change in its speed or position upon the application of a force. The greater the mass of a body, the smaller the change produced by an applied force." [14]

The **atomic mass unit** (measured in u) is based on the actual mass of carbon-12 divided by 12.

2.5 The binding energy of deuterium

The determination of the mass of the neutron is based on the determination of the binding-energy of deuterium. It was observed, that a gamma ray of at least 2.225 MeV could dissolve the nucleus of deuterium *d* into a neutron *n* and ^1H.

$$d + 2.225\,MeV \Rightarrow {}^1H + n$$

The reaction the other way around therefore must also exist, it is an allowed reaction:

$$^{1}H + n \Rightarrow d - 2.225\,MeV$$

If a ^{1}H or better a *p* and a neutron *n* come together and deuterium is created, 2.225 MeV is released as nuclear binding-energy. For clarity we leave out neutrinos or anti-neutrinos in Figure 1.

The p-p reaction goes directly from two ^{1}H (or two protons) to *d* with two versions similar to electron capture and β+ decay. But this reaction is supposed to only happen in stars, it has – as far as we know – not been reproduced on earth. The Q value of 1.442 MeV assigned to this reaction in some sources seems questionable, as it would mean that you get 1.442 MeV as binding-energy, not 2.225 MeV as with the other experimentally proven path. Which one is it?

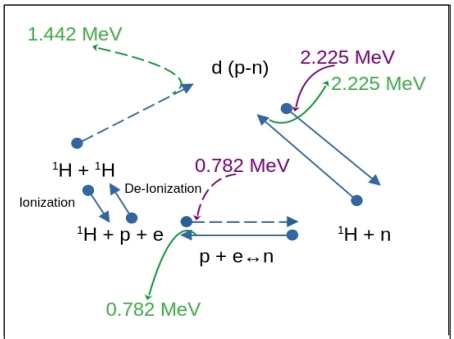

Figure 1: Deuterium and BE + free neutron decay

2.6 Free Neutron decay

It took until 1948, when Arthur Snell and Leonard Miller made the first observation of neutron decay into a proton and an electron. In 1950 Snell, Frances Pleasonton and Rube McCord made the first measurement of the free neutron lifetime. Free neutrons decay with a mean lifetime of 878.4±0.5 s (nearly 15 minutes), which corresponds to a half-life of around 608 seconds. During the decay 0.782 MeV are released. While the neutron lifetime has been studied for decades, there is currently a lack of agreement on its exact value, due to different results from two experimental methods, "bottle" compared to "beam" methods. Another method uses "magnetic traps" [10].

Can you create a neutron inside the nucleus from a proton? Yes, there is electron capture, but that involves a full nucleus. The real question is: Can you create a free neutron from ^{1}H or a free proton and an electron? This is much harder to explain and apparently involves neutron-stars. This is the reason, we marked the reaction at the bottom dashed in figure 1.

2.7 Masses and binding energies/mass defects of some particles and elements

Table 1: Standard model view of mass-defect and binding-energy

Isotope name	Nucleon number	Outer e number	Neutron number	Lit. total BE (MeV)	Lit. AMU	Theoretical mass (AMU)	Mass defect AMU	Mass defect MD (MeV)	BE-MD (MeV)
Electron	0	1	0	0.000000	0.000548579909	0.000548579909	N/A	N/A	N/A
Proton	1	0	0	0.000000	1.007276466621	1.007276466621	N/A	N/A	N/A
Free Neutron	1	0	1	0.000000	1.008664915950	1.008664915950	N/A	N/A	N/A
Hydrogen-1	1	1	0	0.000000	1.007825031900	1.007825047000	N/A	N/A	N/A
Hydrogen-2	2	1	1	2.224566	2.014101777840	2.016489963000	0.002388185160	2.224580392027	0.000
Hydrogen-3	3	1	2	8.481795	3.016049281320	3.025154879000	0.009105597680	8.481810537929	0.000
Helium-3	3	2	1	7.718040	3.016029321970	3.024315010000	0.008285688030	7.718069534437	0.000
Helium-4	4	2	2	28.295664	4.002603254130	4.032979925000	0.030376670870	28.295689766558	0.000
Lithium-6	6	3	3	31.993986	6.015122887400	6.049469888000	0.034347000600	31.994028494717	0.000
Lithium-7	7	3	4	39.245080	7.016003434000	7.058134804000	0.042131370000	39.245122681875	0.000
Beryllium-9	9	4	5	58.164021	9.012183060000	9.074624767000	0.062441707000	58.164081815537	0.000
Boron-10	10	5	5	64.750830	10.012936862000	10.082449814000	0.069512952000	64.750904829805	0.000
Boron-11	11	5	6	76.205052	11.009305167000	11.091114730000	0.081809563000	76.205125456056	0.000

Isotope name	Nucleon number	Outer e number	Neutron number	Lit. total BE (MeV)	Lit. AMU	Theoretical mass (AMU)	Mass defect AMU	Mass defect MD (MeV)	BE-MD (MeV)
Carbon-12	12	6	6	92.161740	12.000000000000	12.098939776000	0.098939776000	92.161817838756	0.000
Carbon-14	14	6	8	105.284466	14.003241988430	14.116269606700	0.113027618270	105.284559829083	0.000
Nitrogen-14	14	7	7	104.658596	14.003074004460	14.115429737300	0.112355732840	104.658702513537	0.000

The factor to convert the mass measured in *u* to MeV in this table is 931.49410242. This table represents the view of the standard model: There is no difference between binding-energy and mass-defect.

2.8 Using total binding-energy values

Typically you see the binding-energy of an isotope expressed as the average binding-energy per nucleon of that isotope. The total numbers are much more expressive and usable in our opinion. For this reason you will find the total binding-energy per isotope atom being used in the table above and also in tables below. The first thing that is noticeable when doing so, is that the energies given off in a nuclear reaction are closely related to the difference between the binding-energy of the source- and the target-isotope. The α decay from Radon-215 to Polonium-211 is a good example. Radon-215 is unstable and emits an α particle after 2.30 µs creating polonium-211. According to the isotope tables nothing else is emitted. In the table we use helium-4 energy-wise as a replacement for the α particle.

Isotope	BE (MeV)	Diff BE (MeV)
Radon-215	1669.220000	
Polonium-211	1649.763424	-19.456576
He-4	28.295660	8.839084

The difference in total binding-energy per atom is equal to the decay energy of 8.839 MeV [12] measured. This is just one of many examples. Using average binding-energy values per nucleon hides this. But as we can see in the following β- decay example from B-12 to C-12, this relation of binding-energies is not true for beta decay.

Isotope	BE (MeV)	Diff BE (MeV)
Boron-12	79.574676	
Carbon-12	92.161728	12.587052

The difference in total binding-energy per atom is 12.587052 MeV while the decay energy is 13.3694 MeV [12]. The difference between those two values is 0.782348 MeV, a well known number, as it is the decay energy of the free neutron decay. This β- decay difference in energies has clearly something to do with the neutron. In other cases the binding-energy difference is even negative because of this difference, as it is the case with the decay from C-14 to N-14 mentioned in the introduction.

2.9 Does the neutron have binding-energy?

If the neutron is fundamental, it can not have binding-energy by definition, the value must be 0. But then there is the free neutron decay, which had not been discovered when the decision about the fundamentality of the neutron was made. The neutron does decay into a proton and an electron, losing the mass difference as energy. That is a strong argument for the neutron being a composite entity, a very closely bound system of two particles. But what about the mass difference between the neutron on one side and the proton and the electron on the other side? If a change in mass is equal to binding-energy, then we must concede that the neutron has negative binding-energy, which sets it apart from any other nucleus. Chadwick's argument against the proton-electron composite was based on the assumption that its binding energy, if existing, would behave like with any other composite known. That assumption was apparently not true.

And Heisenberg's "allowing for simpler calculations" is not a sufficient argument either to make the neutron fundamental.

3 What if the neutron is not fundamental?

In the Structured Atom Model (SAM), created in 2012, the proton-electron-pair (PEP) is the replacement for the free neutron. The name signifies it being a composite of a proton and an electron in a very closely bound system. The atomic nucleus consists only of protons and electrons, nothing more. The ratio in the nucleus is roughly $2p$ to $1e$. Adding PEPs to a nucleus negatively overcharges the nucleus until an inner electron is emitted in a β- decay reaction becoming an outer electron.

In SAM, deuterium (^{2}H) is the first atomic nucleus, we consider hydrogen-1 (^{1}H) to be some kind of proto-atomic nucleus.

Outer electrons are well known. SAM reintroduced the idea of inner electrons in the nucleus. But in order to transition from outer to inner electron, the electron has to gain 0.782347 MeV in mass. The inner electron in the nucleus is closely bound to at least two protons. The inverse reaction gives this amount of mass/energy away when transitioning back to an outer – not closely bound – electron. This process is what we see in β- decay or the decay of the free neutron, the free neutron is essentially an inner electron closely bound to only one proton, and therefore unstable, hence decaying after a few minutes. It should be noted that there is a high chance for a PEP to be absorbed into a nucleus before decaying.

In SAM there are also quasi inner electrons, but for the purpose of this paper we can ignore the differences, as they are equal in mass to inner electrons.

In our book [11] we accepted the negative binding-energy idea for the PEP, calling it a stressed object, that does not want to stay together if not being part of a nucleus. We now abandon this idea – not the idea, that the neutron is a composite of a proton and an electron –, but the idea that the energy being released during free neutron decay has anything to do with binding-energy.

In this paper we do not discuss quarks, neutrinos, anti-neutrinos and spin, as they do not contribute to this discussion.

3.1 The proton-electron-pair and the mass of the inner electron

The energy for the transition from outer to inner electron has to come from somewhere. The process probably needs to be instigated. If the energy is not there or if there is no "need" for it (charge- or energy-imbalance in the nucleus), nothing will happen, an outer electron will not closely bind to at least one proton. The authors consider this to be one reason outer electrons do not "fall" into the nucleus under normal circumstances. All inner electrons of nuclei are bound to at least two protons ($2p$ to $1e$ ratio), this is the preferred state of a nucleus. Small deviations are allowed, as long as an imbalance-threshold is not violated. So when a PEP attaches to a nucleus it makes at least one more connection to protons of the nucleus, becomes stable, but it also slightly unbalances the now bigger nucleus.

3.2 Calculating the mass-defect of deuterium again

We have to look at this now as a process with two steps. We start with dissolving deuterium again. A gamma ray of at least 2.224566 MeV could dissolve the nucleus of deuterium into a PEP and ^{1}H.

$$d + 2.224566\,MeV \Rightarrow {}^1H + PEP$$

But this is only the first step. The PEP decays into a proton and an electron, effectively an ^{1}H and giving of 0.782347 MeV.

$$PEP \Rightarrow p + e + 0.782347 \Rightarrow {}^1H + 0.782347$$

If we combine this:

$$d + 2.224566\,MeV \Rightarrow {}^1H + {}^1H + 0.782347\,MeV$$

Moving the pieces around, we get

$$d - 2\,{}^1H \Rightarrow 0.782347\,MeV - 2.224566\,MeV = -1.44219\,MeV$$

So the overall mass-defect of deuterium is just 1.44219 MeV, not 2.224566 MeV. The other way around therefore must also be true, first the PEP:

$${}^1H + 0.782347\,MeV \Rightarrow PEP$$

and then creating d out of ^{1}H and a PEP:

$${}^1H + PEP \Rightarrow d - 2.224566\,MeV$$

If a ^{1}H and a PEP come together and deuterium is created, 2.224566 MeV is released as nuclear binding energy. But before that 0.782347 MeV had to be spent to change the mass of an electron to become an inner electron, so overall only 1.44219 MeV are released in the process, looking at the complete process energy balance sheet.

$$2\,{}^1H + 0.782347\,MeV \Rightarrow d - 2.224566\,MeV$$

Again moving the pieces around, we get

$$2\,{}^1H - d \Rightarrow 2.224566\,MeV - 0.782347\,MeV = 1.44219\,MeV$$

In the SAM we now must accept that mass-defect and total binding-energy values differ.

3.3 What happens when a deuterium nucleus is created?

In SAM the deuterium is made up of one outer electron e_o and a nucleus which consists of two protons p and one inner electron e_i. The inner electron has 0.782347 MeV more mass than an outer electron. When a deuterium is created from smallest constituents, in one path (reverse from experimental results) the first step is the creation of a PEP, ionizing ^{1}H and impregnating the free electron with 0.782347 MeV so it can closely bind with the proton. This PEP is then captured by an ^{1}H to create deuterium, releasing 2.224566 MeV in the process. The second path (not experimentally verified) goes directly from two ^{1}H to d (p-p reaction), but the energy numbers usually given (1.442 MeV) are wrong, because one electron has to gain mass first. When corrected there is not much difference between the path through the PEP and the direct path in SAM.

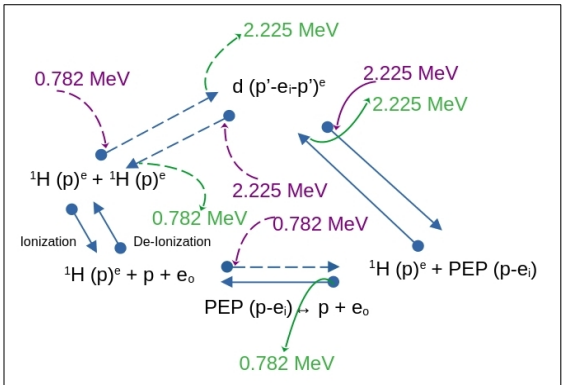

Figure 2: New mass-defect + BE of deuterium

Because the path from a PEP to p + e_o exists, we can assume, the path from p + e_o to a PEP exists too. But to be fair, this reaction – as far as we know – has not been witnessed experimentally.

The released binding-energy of 2.224566 MeV when d is created has to come from somewhere. Remember, binding-energy is not what binds the nucleus together, it is an absence of energy, as it is emitted. Here we propose that the source is the two protons in the nucleus. Each proton *p* gives away 1.112283 MeV of it's mass, making them effectively a *p'*. This means: **A proton in a nucleus has less mass than a proton outside the nucleus or an ^{1}H**. Only after a proton in deuterium is reconstituted ($p' \rightarrow p$) by accepting 1.112283 MeV, does it come free of the nucleus. In case of deuterium one of them "grabs" the inner electron e_i, becoming a PEP, the other proton reconstitutes similarly and "grabs" the outer electron e_o becoming ^{1}H. The authors consider this an important research topic.

3.4 New masses and mass defects of some particles and elements

If we apply what was discussed above, we end up with the following table for the elements up to nitrogen. The main difference is that we start with the mass of the outer electron, **the electron mass gain is no longer hidden inside the supposedly fundamental "neutron"**.

Table 2: SAM view of mass-defect and binding-energy

Isotope name	Proton number	Outer e number	Inner e number	Lit. total BE (MeV)	Lit. mass (u)	New theoretical mass (u)	New mass-defect NMD (u)	NMD (MeV)	BE – NMD (MeV)
Outer electron	0	1	0	N/A	0.000548579909	0.000548579909	N/A	N/A	N/A
Inner electron	0	0	1	N/A	0.001388449329	0.000548579909	-0.000839869420	-0.782347	N/A
Proton	1	0	0	N/A	1.007276466621	1.007276466621	N/A	N/A	N/A
PEP	1	0	1	N/A	1.008664915950	1.007825046530	-0.000839869420	-0.782347	N/A
Hydrogen-1	1	1	0	N/A	1.007825031900	1.007825046530	N/A	N/A	N/A
Hydrogen-2	2	1	1	2.224566	2.014101777840	2.015650093060	0.001548315220	1.442219	0.782
Hydrogen-3	3	1	2	8.481795	3.016049281320	3.023475139590	0.007425858270	6.917101	1.565
Helium-3	3	2	1	7.718040	3.016029321970	3.023475139590	0.007445817620	6.935693	0.782
Helium-4	4	2	2	28.295664	4.002603254130	4.031300186120	0.028696931990	26.730966	1.565
Lithium-6	6	3	3	31.993986	6.015122887400	6.046950279180	0.031827391780	29.646945	2.347
Lithium-7	7	3	4	39.245080	7.016003434000	7.054775325710	0.038771891710	36.115685	3.129
Beryllium-9	9	4	5	58.164021	9.012183060000	9.070425418771	0.058242358771	54.252277	3.912
Boron-10	10	5	5	64.750830	10.012936862000	10.078250465301	0.065313603301	60.839095	3.912
Boron-11	11	5	6	76.205052	11.009305167000	11.086075511831	0.076770344831	71.510970	4.694
Carbon-12	12	6	6	92.161740	12.000000000000	12.093900558361	0.093900558361	87.467646	4.694
Carbon-14	14	6	8	105.284466	14.003241988430	14.109550651420	0.106308662990	99.025690	6.259
Nitrogen-14	14	7	7	104.658596	14.003074004460	14.109550651420	0.106476646960	99.182167	5.476

In table 2 we start with different theoretical masses than in table 1. **The result is a difference between mass-defect and binding-energy. Those are no longer equal in SAM.** Coming back to deuterium as an example: The energy of 2.224566 MeV is well known from experiments to dissolve deuterium into a ^{1}H and a PEP. This is therefore the binding-energy value. The SAM does not change that. But the PEP dissolves by itself, returning 0.782347 MeV to the overall energy balance. Therefore the new mass-defect value is only 1.442219 MeV. In the inverse reaction 0.782347 MeV needs to be spend first to create a heavy electron, which then binds with a proton to create a PEP. This PEP again binds to a ^{1}H, creating deuterium and releasing 2.224566 MeV. But as we had to spend 0.782347 MeV first to get a release of 2.224566 MeV, the actual mass-defect is only 1.442219 MeV.

4 Consequences

4.1 Charts of binding-energy and new mass-defect differences

If we look at the numbers in table 2 the rule becomes clearly visible. The difference between the old mass-defect, which is equal to the binding-energy and the new mass-defect is 0.782347 MeV times the number of inner electrons in a nucleus. To visualize this difference of binding-energies/mass defects of nuclei, given as averages (figure 3) and as total values (figure 4), old and new, are plotted against the number of nucleons in the figures below. The values used can be found in table 3 in the appendix.

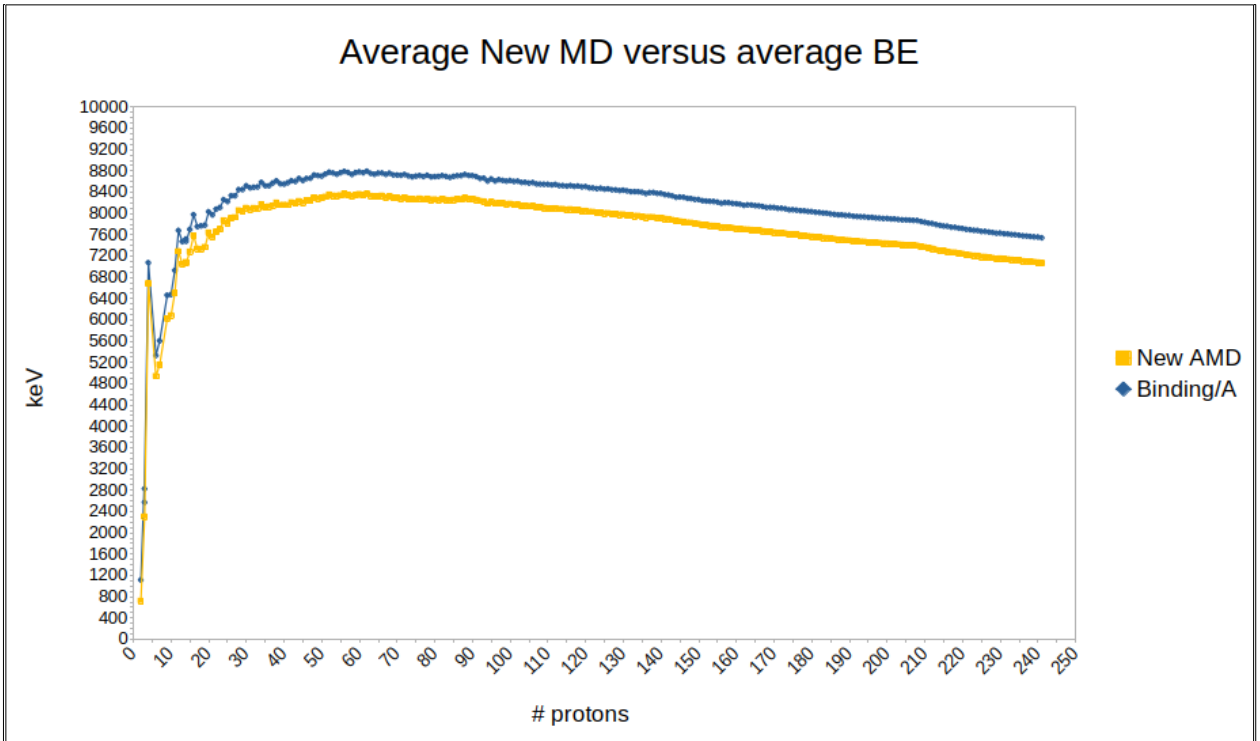

Figure 3: Average New Mass-Defect versus Average Binding-Energy (equal to old mass-defect)

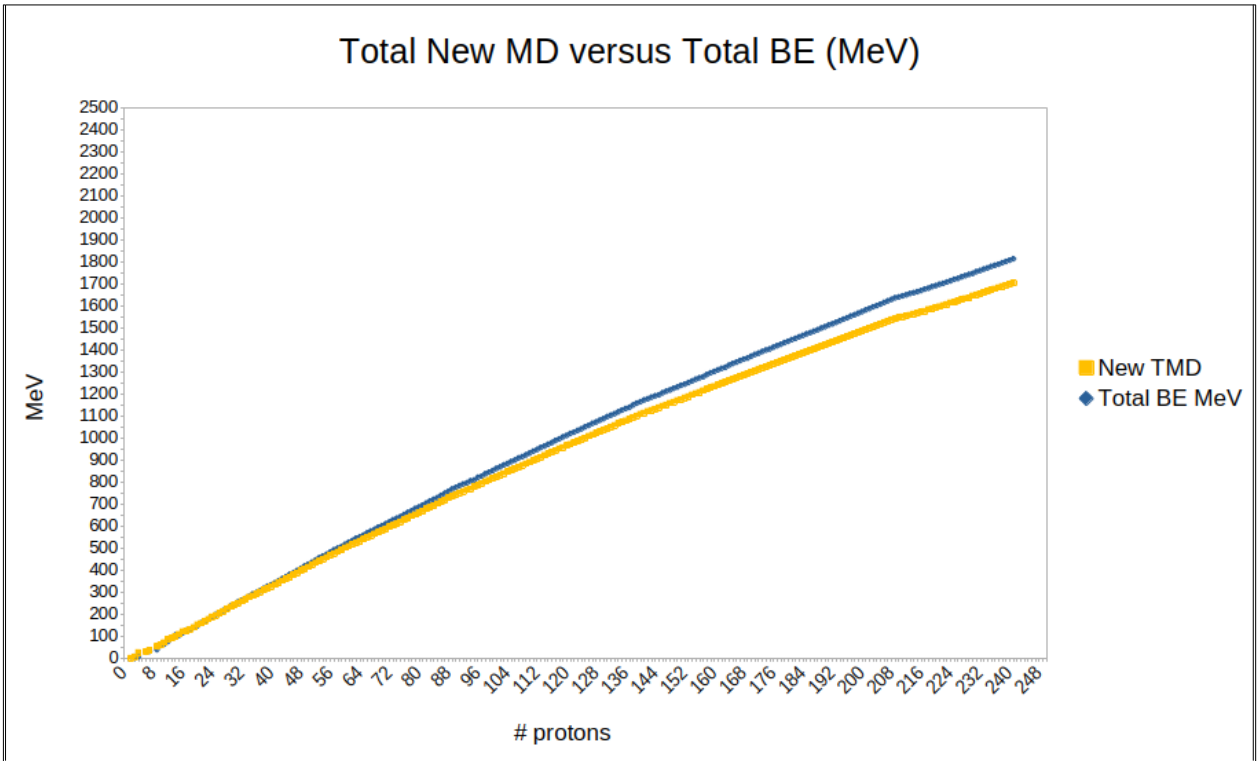

Figure 4: Total New Mass-Defect versus Total Binding-Energy (equal to old mass-defect)

4.2 β decay

In the introduction we already talked about strange β- cases of the total binding energy difference becoming negative an the average binding-energy going down during such a decay step. In [11] we tried to explain the issue away with the minimum bounding sphere (MBS) radius shrinking as an option why the reaction could still happen. The minimum bounding sphere is the smallest sphere that encompasses the structure of a nucleus and gives, in combination with the number of nucleons, a measure of nucleus density (densest packing). This explanation attempt does not satisfy and we have abandoned it. Instead we now look at the difference of the new mass-defect (NMD) energies as the relevant numbers.

The Diff-NMD energy values are an exact match with literature decay energy values and the NMD difference values, both average and total go into the right direction. Here we look at just two examples, a more thorough list can be found in the appendix.

4.2.1 β- decay from H-3 to He-3

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	Average BE (KeV)	Average NMD (KeV)	Total BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Hydrogen-3	1	12.32 y	3.00000	37.6991	2827.2650	2305.7000	8.481795		6.917101	
Helium-3	-1	Stable	2.15023	13.8810	2572.6800	2311.8980	7.718040	**-0.763755**	6.935693	0.018592

Decay energy: **0.018592 MeV** [12].

4.2.2 β- decay from C-14 to N-14

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	Average BE (KeV)	Average NMD (KeV)	Total BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Carbon-14	2	5,730 y	3.51367	12.9791	7520.3190	7073.2640	105.284466		99.025690	
Nitrogen-14	0	Stable	3.46438	12.4405	7475.6140	7084.4410	104.658596	**-0.625870**	99.182167	0.156477

Decay energy: **0.156476 MeV** [12].

4.3 α decay

α decay is another well known reaction and we have to look at the Diff-NMD values too.

4.3.1 α decay from Radon-215 to Polonium-211

This decay step we looked at before, but now it is expanded by the NMD energy values.

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Radon-215	1669.220000		1568.297247	
Polonium-211	1649.763424	-19.456576	1550.405355	-17.891892
He-4	28.295660	8.839084	26.730966	8.839074

Decay energy: **8.839 MeV** [12].

4.3.2 α decay from Nitrogen-15 + proton to Carbon-12

This reaction is the last part of the CNO-I cycle.

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Nitrogen-15	115.492000		109.233124	
Proton	0.000000		0.000000	
Carbon-12	92.161728	-23.330272	87.467646	-21.765478
He-4	28.295660	4.965388	26.730966	4.965488

Decay energy: 4**.96 MeV** [13].

It is obvious that using Diff-BE or Diff-NMD yields the same results in these cases.

5 Nucleosynthesis

We touched upon reactions in this paper, which belong to the realm of nucleosynthesis. Nucleosynthesis is supposed to be the answer to the question, how all the elements were/are created in the universe and in which quantities. Contributing to the creation of elements are the big-bang, neutron-stars, black-holes, anti-matter, supernovae and stars in various sizes/masses according to those theories.

5.1 CNO-I

The CNO-I cycle is supposed to create helium-4 with carbon as a catalyzer and protons as fuel. There are variations of this process with different catalyzers in the carbon-nitrogen-oxygen range, which add protons to the starting element (the catalyzer), then decay with β+ reactions to the next element until an α particle is released and again the catalyzer element. The cycle repeats.

5.1.1 Carbon-12 + proton to Nitrogen-13

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Carbon-12	92.161728		87.467646	
Proton	0.000000		0.000000	
Nitrogen-13	94.105219	1.943491	89.411137	1.943491

Decay energy: 1**.95 MeV** [13].

5.1.2 β+ decay from N-13 to C-13

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Nitrogen-13	94.105219		89.411137	

Carbon-13	97.108000	3.002781	91.631608	2.220471

Decay energy: **2.22047 MeV** [12].

5.1.3 Carbon-13 + proton to Nitrogen-14

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Carbon-13	97.108000		91.631608	
Proton	0.000000		0.000000	
Nitrogen-14	104.658596	7.550596	99.18	7.550559

Decay energy: 7**.55 MeV** [13].

5.1.4 Nitrogen-14 + proton to Oxygen-15

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Nitrogen-14	104.658596		99.18	
Proton	0.000000		0.000000	
Oxygen-15	111.955380	7.296784	106.478951	7.296784

Decay energy: 7**.35 MeV** [13].

5.1.5 β+ decay from O-15 to N-15

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Oxygen-15	111.955380		106.478951	
Nitrogen-15	115.492000	3.536620	109.233124	2.754173

Decay energy: **2.7542 MeV** [12].

5.1.6 β+ decay from N-15 to C-12+He-4

Isotope	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Nitrogen-15	115.492000		109.233124	
Proton	0.000000		0.000000	
Carbon-12	92.161728	-23.330272	87.467646	-21.765478
He-4	28.295660	4.965388	26.730966	4.965488

Decay energy: 4**.96 MeV** [13].

The value from “nitrogen-14 + proton to oxygen-15” given by [13] is wrong in our opinion. It is claimed in [13] the sum of the values is 26.73 MeV, which is true, but not with their given numbers. The numbers given here on the other hand sum up nicely to 26.730966 MeV which is an exact match to the new mass-defect number of helium-4.

6 Discussion and Conclusion

In this paper we found that assuming the neutron to be a fundamental particle on the level of the proton masks a difference between total binding-energy and mass-defect, which is 0.782347 MeV times the number of inner electrons in a nucleus. The transition from inner to outer electron and vice versa does not contribute to binding-energy, but inversely to the mass-defect. When applying NMD instead of BE to nuclear reactions involving electrons (β-type decays) we find that inconsistencies in the current model vanish. Not only does the overall direction of the energies fit in all cases we looked at, but also the release-energy numbers are a fit. When we look at α decay, we find that binding-energy and new mass-defect work equally well. We must conclude that for reactions the use of the difference of new mass-defect values yields better results, while the binding-energy works fine for disintegration experiments. Reaction-ener-

gies seem to be represented by NMD differences between source- and target isotopes, not binding-energy differences.

When we look at the arguments of how and why the idea of an atomic nucleus consisting of protons and electrons was abandoned, favoring protons and neutrons, these can not satisfy in our opinion. The decision was premature and in hindsight ill-advised. The Structured Atom Model follows a “clean-slate” path, nothing is sacrosanct. Therefore we again followed the idea, that the atomic nucleus is made up of protons and electrons and see where it leads us. This paper, close to 15 years after SAM was created, shows a case where SAM with its inner-electron approach leads to better and consistent results.

Possibly one good use-case for the average binding-energy value per nucleon might be the notion of what average amount the proton mass changes per element and isotope. But we can not even be sure that every proton in a nucleus changes its mass by the same value, we only know the average change per nucleon and the total change. There might be different values based on the structure of the nucleus and the position of protons within the nucleus.

The term nuclear binding-energy is clearly misleading as the term suggests an active energy binding something together. Instead it is the absence of this energy from a bound system that is represented by the term binding-energy.

In SAM the inner electron mass (energy) gain is no longer hidden inside the supposedly fundamental “neutron”. In our book [11], we talked about negatively overcharging the nucleus negatively, when adding PEPs to it, causing a beta- type reaction to relieve the excess charge. Therefore we now can add over-energizing it to the possible causes for a β- reaction.

7 References

[1] Chadwick, J.: Possible Existence of a Neutron; in *Nature* 129, p. 312, 1932

[2] Chadwick, J.: The existence of a neutron; in *Proceedings of the Royal Society of London. Series A*, Volume 136, Issue 830, p. 692–708, 1932

[3] Heisenberg, W.: Über den Bau der Atomkerne I; in *Zeitschrift für Physik* 77, p. 1–11, 1932

[4] Heisenberg, W.: Über den Bau der Atomkerne II; in *Zeitschrift für Physik* 78, p. 156–164, 1932

[5] Heisenberg, W.: Über den Bau der Atomkerne III; *Zeitschrift für Physik* 80, p. 587–596, 1933

[6] Gauthier-Villars: *Structure et propriétés des noyaux atomiques: rapports et discussions du septième Conseil de physique tenu à Bruxelles du 22 au 29 octobre 1933, sous les auspices de l'Institut international de physique Solvay*; Paris, 1935

[7] Chadwick, J. and Goldhaber, M.: The nuclear photoelectric effect; in *Proceedings of the Royal Society of London. Series A*, Volume 151, Issue 873, p. 479–493, 1935

[8] Greene, G. L. and Kessler, E. G. and Deslattes, R. D. and Börner, H.G.: New determination of the deuteron binding energy and the neutron mass; in *Physical Review Letters* 56, p. 819-822, 1986

[9] Kessler, E.G. Jr and Dewey, M.S. and Deslattes, R.D. and Henins, A. and Börner, H.G. and Jentschel, M. and Doll, C. and Lehmann H.: The deuteron binding energy and the neutron mass; in *Physics Letters A*, Volume 255, Issues 4–6, p. 221-229, 1999

[10] Wietfeldt, F. E. and Greene, G. L.: Colloquium: The neutron lifetime; in *Reviews of Modern Physics* 83, 1173-1192, 2011

[11] Kaal, J. E. and Sorensen, J. A. and Otte, A. and Emming, J. G.: *The Nature of the Atom. An introduction to the Structured Atom Model*, Curtis Press, 2021

[12] Chemlin https://www.chemlin.org/isotope/<Isotope-Name> (last accessed 19.04.2026)
e.g. https://www.chemlin.org/isotope/Hydrogen-3

[13] Wikipedia: CNO Cycle; https://en.wikipedia.org/wiki/CNO_cycle (last accessed 19.04.2026)

[14] Encyclopedia Britannica: Mass; https://www.britannica.com/science/mass-physics (last accessed 19.04.2026)

8 Appendix

8.1 New Mass-Defect values compared to Binding-Energy

Table 3: Binding-energy and new mass-defect

Isotope	Old Average BE/MD (keV)	New Average MD (keV)	Old Total BE/MD (MeV)	New Total MD (MeV)
H-2	1112.283	721.110	2.224566	1.442219
H-3	2827.265	2305.700	8.481795	6.917101
He-3	2572.680	2311.898	7.718040	6.935693
He-4	7073.915	6682.742	28.295660	26.730966
Li-6	5332.331	4941.158	31.993986	29.646945
Li-7	5606.439	5159.384	39.245073	36.115685
Be-9	6462.668	6028.031	58.164012	54.252277
B-10	6475.083	6083.910	64.750830	60.839095
B-11	6927.732	6500.997	76.205052	71.510970
C-12	7680.144	7288.971	92.161728	87.467646
C-13	7469.849	7048.585	97.108037	91.631608
C-14	7520.319	7073.264	105.284466	99.025690
N-14	7475.614	7084.441	104.658596	99.182167
N-15	7699.460	7282.208	115.491900	109.233124
O-16	7976.206	7585.033	127.619296	121.360520
O-17	7750.728	7336.544	131.762376	124.721253
O-18	7767.097	7332.460	139.807746	131.984276
F-19	7779.018	7367.256	147.801342	139.977872
Ne-20	8032.240	7641.067	160.644800	152.821330
Ne-21	7971.713	7561.912	167.405973	158.800156
Ne-22	8080.465	7653.730	177.770230	168.382066
Na-23	8111.493	7703.312	186.564339	177.176175
Mg-24	8260.709	7869.536	198.257016	188.868852
Mg-25	8223.502	7816.682	205.587550	195.417039
Mg-26	8333.870	7912.606	216.680620	205.727762
Al-27	8331.553	7925.892	224.951931	213.999073

Isotope	Old Average BE/MD (keV)	New Average MD (keV)	Old Total BE/MD (MeV)	New Total MD (MeV)
Si-28	8447.744	8056.571	236.536832	225.583974
Si-29	8448.635	8043.973	245.010415	233.275210
Si-30	8520.654	8103.402	255.619620	243.102068
P-31	8481.167	8077.375	262.916177	250.398625
S-32	8493.129	8101.956	271.780128	259.262576
S-33	8497.630	8094.603	280.421790	267.121891
S-34	8583.498	8169.314	291.838932	277.756686
Cl-35	8520.278	8117.928	298.209730	284.127484
Ar-36	8519.909	8128.736	306.716724	292.634478
Cl-37	8570.281	8147.391	317.100397	301.453457
Ar-38	8614.280	8202.518	327.342640	311.695700
K-39	8557.025	8155.821	333.723975	318.077035
Ca-40	8551.303	8160.130	342.052120	326.405180
K-41	8576.072	8156.276	351.618952	334.407318
Ca-42	8616.563	8206.762	361.895646	344.684012
Ca-43	8600.663	8182.198	369.828509	351.834528
Ca-44	8658.175	8231.440	380.959700	362.183372
Sc-45	8618.931	8201.679	387.851895	369.075567
Ti-46	8656.451	8248.270	398.196746	379.420418
Ti-47	8661.227	8245.085	407.077669	387.518994
Ti-48	8723.006	8299.235	418.704288	398.363266
Ti-49	8711.157	8280.068	426.846693	405.723324
Cr-50	8701.032	8294.212	435.051600	414.710578
V-51	8742.099	8312.575	445.847049	423.941333
Cr-52	8775.989	8354.725	456.351428	434.445712
Cr-53	8760.198	8332.121	464.290494	441.602431
Fe-54	8736.382	8330.721	471.764628	449.858912
Mn-55	8765.022	8338.287	482.076210	458.605800
Fe-56	8790.354	8371.240	492.259824	468.789414
Fe-57	8770.279	8344.792	499.905903	475.653146
Ni-58	8732.059	8327.397	506.459422	482.989012
Co-59	8768.035	8343.711	517.314065	492.278961
Ni-60	8780.774	8363.522	526.846440	501.811336
Ni-61	8765.025	8341.788	534.666525	508.849074
Ni-62	8794.553	8365.524	545.262286	518.662488
Cu-63	8752.138	8329.919	551.384694	524.784896
Zn-64	8735.905	8320.283	559.097920	532.498122
Cu-65	8757.096	8323.796	569.211240	541.046748
Zn-66	8759.632	8332.897	578.135712	549.971220
Zn-67	8734.152	8302.110	585.188184	556.241345
Zn-68	8755.680	8318.486	595.386240	565.657054
Ga-69	8724.579	8293.721	601.995951	572.266765
Ge-70	8721.700	8296.997	610.519000	580.789814
Ga-71	8717.604	8276.845	618.949884	587.656004

Isotope	Old Average BE/MD (keV)	New Average MD (keV)	Old Total BE/MD (MeV)	New Total MD (MeV)
Ge-72	8731.745	8297.108	628.685640	597.391760
Ge-73	8705.049	8265.649	635.468577	603.392350
Se-74	8687.715	8264.825	642.890910	611.597030
As-75	8700.874	8262.760	652.565550	619.706976
Se-76	8711.477	8279.127	662.072252	629.213678
Se-77	8694.690	8257.795	669.491130	635.850209
Se-78	8717.806	8276.482	679.988868	645.565600
Br-79	8687.594	8251.856	686.319926	651.896658
Kr-80	8692.928	8262.637	695.434240	661.010972
Br-81	8695.946	8251.650	704.371626	668.383664
Kr-82	8710.675	8271.797	714.275350	678.287388
Kr-83	8695.729	8252.713	721.745507	684.975198
Sr-84	8677.512	8249.084	728.911008	692.923046
Rb-85	8697.441	8255.645	739.282485	701.729829
Sr-86	8708.456	8271.797	748.927216	711.374560
Rb-87	8710.983	8261.358	757.855521	718.738171
Sr-88	8732.595	8288.080	768.468360	729.351010
Y-89	8713.978	8274.457	775.544042	736.426692
Zr-90	8709.969	8275.332	783.897210	744.779860
Zr-91	8693.314	8254.856	791.091574	751.191877
Mo-92	8657.730	8232.541	796.511160	757.393810
Nb-93	8664.184	8226.743	805.769112	765.087068
Tc-94	8608.736	8184.271	809.221184	769.321487
Mo-95	8648.720	8212.253	821.628400	780.164009
Ru-96	8609.412	8185.641	826.503552	785.821508
Mo-97	8635.092	8191.493	837.603924	794.574839
Ru-98	8620.313	8189.224	844.790674	802.543936
Ru-99	8608.712	8174.075	852.262488	809.233403
Ru-100	8619.359	8181.245	861.935900	818.124468
Ru-101	8601.365	8159.842	868.737865	824.144086
Ru-102	8607.427	8162.563	877.957554	832.581428
Rh-103	8584.192	8143.647	884.171776	838.795650
Pd-104	8584.848	8148.539	892.824192	847.448066
Pd-105	8570.650	8131.045	899.918250	853.759777
Pd-106	8579.992	8137.154	909.479152	862.538332
Ag-107	8553.900	8115.201	915.267300	868.326480
Cd-108	8550.019	8115.382	923.402052	876.461232
Ag-109	8547.915	8102.910	931.722735	883.217221
Pd-110	8547.162	8091.978	940.187820	890.117612
Cd-111	8537.079	8093.044	947.615769	898.327908
Cd-112	8544.730	8097.675	957.009760	906.939552
In-113	8522.929	8079.830	963.090977	913.020769
Sn-114	8522.566	8083.354	971.572524	921.502316
Sn-115	8514.069	8071.873	979.117935	928.265380

Isotope	Old Average BE/MD (keV)	New Average MD (keV)	Old Total BE/MD (MeV)	New Total MD (MeV)
Sn-116	8523.116	8077.988	988.681456	937.046554
Sn-117	8509.611	8061.600	995.624487	943.207238
Sn-118	8516.533	8065.689	1004.950894	951.751298
Sn-119	8499.449	8045.819	1011.434431	957.452488
Sn-120	8504.492	8048.123	1020.539040	965.774750
Sb-121	8482.066	8029.469	1026.329986	971.565696
Te-122	8478.140	8029.252	1034.333080	979.568790
Te-123	8465.546	8013.947	1041.262158	985.715521
Te-124	8473.279	8019.013	1050.686596	994.357612
Te-125	8458.045	8001.154	1057.255625	1000.144294
Te-126	8463.248	8003.774	1066.369248	1008.475570
I-127	8445.487	7989.631	1072.576849	1014.683171
Xe-128	8443.298	7991.004	1080.742144	1022.848466
Xe-129	8431.390	7976.537	1087.649310	1028.973285
Xe-130	8437.731	7980.359	1096.905030	1037.446658
Xe-131	8423.736	7963.883	1103.509416	1043.268697
Ba-132	8409.375	7958.933	1110.037500	1050.579128
Cs-133	8409.978	7951.158	1118.527074	1057.504008
Ba-134	8408.171	7952.775	1126.694914	1065.671848
Ba-135	8397.533	7939.715	1133.666955	1071.861542
Ce-136	8373.760	7925.061	1138.831360	1077.808294
Ba-137	8391.827	7929.271	1149.680299	1086.310192
Ba-138	8393.420	7928.547	1158.291960	1094.139506
La-139	8378.025	7916.497	1164.545475	1100.393021
Ce-140	8376.317	7918.085	1172.684380	1108.531926
Pr-141	8353.992	7899.010	1177.912872	1113.760418
Nd-142	8346.030	7894.252	1185.136260	1120.983806
Nd-143	8330.488	7876.398	1191.259784	1126.324983
Sm-144	8303.679	7858.176	1195.729776	1131.577322
Nd-145	8309.187	7850.570	1204.832115	1138.332620
Nd-146	8304.092	7843.257	1212.397432	1145.115590
Pm-147	8284.372	7826.672	1217.802684	1150.520842
Sm-148	8279.633	7825.026	1225.385684	1158.103842
Sm-149	8263.466	7806.659	1231.256434	1163.192245
Sm-150	8261.621	7802.644	1239.243150	1170.396614
Eu-151	8239.297	7783.360	1244.133847	1175.287311
Gd-152	8233.401	7780.463	1251.476952	1182.630416
Eu-153	8228.699	7768.495	1258.990947	1188.579717
Gd-154	8224.796	7767.580	1266.618584	1196.207354
Gd-155	8213.251	7753.938	1273.053905	1201.860328
Dy-156	8192.433	7741.079	1278.019548	1207.608318
Gd-157	8203.504	7740.076	1287.950128	1215.191857
Gd-158	8201.819	7736.372	1295.887402	1222.346784
Tb-159	8188.800	7726.280	1302.019200	1228.478582

Isotope	Old Average BE/MD (keV)	New Average MD (keV)	Old Total BE/MD (MeV)	New Total MD (MeV)
Gd-160	8183.014	7713.606	1309.282240	1234.176928
Dy-161	8173.310	7711.677	1315.902910	1241.579945
Er-162	8152.397	7698.443	1320.688314	1247.147696
Dy-163	8161.785	7696.217	1330.370955	1254.483296
Dy-164	8158.714	7691.214	1338.029096	1261.359090
Ho-165	8146.964	7682.297	1344.249060	1267.579054
Er-166	8141.959	7680.091	1351.565194	1274.895188
Er-167	8131.746	7667.959	1358.001582	1280.549229
Yb-168	8111.898	7655.529	1362.798864	1286.128858
Tm-169	8114.473	7651.546	1371.345937	1293.111237
Er-170	8111.959	7642.551	1379.033030	1299.233636
Yb-171	8097.882	7635.794	1384.737822	1305.720775
Yb-172	8097.429	7633.479	1392.757788	1312.958394
Yb-173	8087.427	7621.637	1399.124871	1318.543130
Hf-174	8068.533	7609.916	1403.924742	1324.125348
Lu-175	8069.140	7604.202	1412.099500	1330.735412
Hf-176	8061.359	7599.063	1418.799184	1337.435096
Hf-177	8051.835	7587.731	1425.174795	1343.028360
Hf-178	8049.442	7583.550	1432.800676	1349.871894
Hf-179	8038.546	7570.886	1438.899734	1355.188605
Hf-180	8034.930	7565.522	1446.287400	1361.793924
Ta-181	8023.400	7556.585	1452.235400	1367.741924
W-182	8018.308	7554.058	1459.332056	1374.838580
W-183	8008.322	7542.334	1465.522926	1380.247103
W-184	8005.077	7537.370	1472.934168	1386.875998
Re-185	7991.009	7525.830	1478.336665	1392.278495
Os-186	7982.831	7520.153	1484.806566	1398.748396
Os-187	7973.780	7509.392	1491.096860	1404.256343
Os-188	7973.864	7507.785	1499.086432	1411.463568
Os-189	7963.002	7495.250	1505.007378	1416.602167
Os-190	7962.104	7492.696	1512.799760	1423.612202
Ir-191	7948.113	7481.162	1518.089583	1428.902025
Pt-192	7942.491	7477.972	1524.958272	1435.770714
Ir-193	7938.133	7467.914	1532.059669	1441.307417
Pt-194	7935.941	7468.146	1539.572554	1448.820302
Pt-195	7926.552	7457.144	1545.677640	1454.143041
Pt-196	7926.529	7455.524	1553.599684	1461.282738
Au-197	7915.654	7447.040	1559.383838	1467.066892
Hg-198	7911.552	7445.305	1566.487296	1474.170350
Hg-199	7905.279	7437.443	1573.150521	1480.051228
Hg-200	7905.895	7436.487	1581.179000	1487.297360
Hg-201	7897.560	7426.595	1587.409560	1492.745573
Hg-202	7896.850	7424.343	1595.163700	1499.717366
Tl-203	7886.053	7415.874	1600.868759	1505.422425

Isotope	Old Average BE/MD (keV)	New Average MD (keV)	Old Total BE/MD (MeV)	New Total MD (MeV)
Pb-204	7879.932	7412.058	1607.506128	1512.059794
Tl-205	7878.394	7405.169	1615.070770	1518.059742
Pb-206	7875.362	7404.435	1622.324572	1525.313544
Pb-207	7869.866	7397.434	1629.062262	1531.268887
Pb-208	7867.453	7393.531	1636.430224	1537.854502
Bi-209	7847.987	7376.333	1640.229283	1541.653561
Po-210	7834.346	7364.938	1645.212660	1546.636938
Po-211	7818.784	7347.893	1649.763424	1550.405355
Po-212	7810.243	7337.883	1655.771516	1555.631100
Bi-213	7791.021	7313.532	1659.487473	1557.782363
At-214	7776.366	7304.764	1664.142324	1563.219561
Rn-215	7763.814	7294.406	1669.220010	1568.297247
Po-216	7758.819	7280.718	1675.904904	1572.635100
Po-217	7741.360	7261.857	1679.875120	1575.822969
Rn-218	7738.752	7265.037	1687.047936	1583.778132
Rn-219	7723.777	7248.653	1691.507163	1587.455012
Rn-220	7717.254	7240.734	1697.795880	1592.961382
Rn-221	7701.393	7223.489	1702.007853	1596.391008
Rn-222	7694.497	7215.221	1708.178334	1601.779142
Fr-223	7683.664	7206.538	1713.457072	1607.057880
Ra-224	7679.922	7204.926	1720.302528	1613.903336
Fr-225	7662.940	7183.101	1724.161500	1616.197614
Ra-226	7661.962	7184.246	1731.603412	1623.639526
Ac-227	7650.707	7175.095	1736.710489	1628.746603
Ra-228	7642.428	7162.039	1742.473584	1632.945004
Ra-229	7628.485	7146.778	1746.923065	1636.612138
Th-230	7630.996	7154.785	1755.129080	1645.600500
Pa-231	7618.426	7144.276	1759.856406	1650.327826
Th-232	7615.033	7136.183	1766.687656	1655.594382
U-233	7603.956	7130.519	1771.721748	1661.410821
U-234	7600.715	7125.957	1778.567310	1667.474036
U-235	7590.914	7114.848	1783.864790	1671.989169
Np-236	7579.214	7105.165	1788.694504	1676.818883
Np-237	7574.989	7099.639	1795.272393	1682.614425
Pu-238	7568.360	7095.007	1801.269680	1688.611712
Pu-239	7560.318	7085.672	1806.916002	1693.475687
Pu-240	7556.042	7080.114	1813.450080	1699.227418
Am-241	7543.278	7069.325	1817.929998	1703.707336

8.2 β decay energies

We show here as reference all the β decay cases that were listed in [11] up to argon with some corrections. The cases where the BE energy value differences are negative are:

- hydrogen-3 to helium-3
- beryllium-10 to boron-10

- carbon-14 to nitrogen-14
- sulfur-35 to chlorine-35
- chlorine-36 to argon-36
- argon-39 to potassium-39

All these strange cases mentioned above are gone when the NMD (new mass-defect) energy is used instead of BE. No new cases appear. The Diff-NMD energy values are an exact match with literature decay energy values in all cases listed.

8.2.1 β- decay from H-3 to He-3

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Hydrogen-3	1	12.32 y	3.00000	37.6991	8.481795		6.917101	
Helium-3	-1	Stable	2.15023	13.8810	7.718040	**-0.763755**	6.935693	0.018592

Decay energy: **0.018592 MeV** [12].

8.2.2 β- decay from Li-8 to Be-8

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Lithium-8	+2/+1 PEP gap	839.40 ms	2.98165	13.8793	41.277696		37.365961	
Beryllium-8	0	8.19 × 10−17 s	2.98165	13.8793	56.499480	15.221784	53.370092	16.004131

Decay energy: **16.00413 MeV** [12].

8.2.3 β- decay from Li-9 to Be-9

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Lithium-9	+3/+1 PEP gap	178.3 ms	2.98288	12.3525	45.339912		40.645830	
Beryllium-9	1	Stable	2.90211	11.3760	58.164012	12.824100	54.252277	13.606447

Decay energy: **13.60645 MeV** [12].

8.2.4 β- decay from Be-10 to B-10

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Beryllium-10	2	1.39 × 106 y	2.99710	11.2770	64.976300		60.282218	
Boron-10	0	Stable	3.05071	11.8931	64.750830	**-0.225470**	60.839095	0.556877

Decay energy: **0.55688 MeV** [12].

8.2.5 β- decay from B-12 to C-12

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Boron-12	2	20.20 ms	3.26036	12.0978	79.574676		74.098247	
Carbon-12	0	Stable	2.90211	8.5320	92.161728	12.587052	87.467646	13.369399

Decay energy: **13.3694 MeV** [12].

8.2.6 β- decay from C-14 to N-14

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Carbon-14	2	5,730 y	3.51367	12.9791	105.284466		99.025690	
Nitrogen-14	0	Stable	3.46438	12.4405	104.658596	**-0.625870**	99.182167	0.156477

Decay energy: **0.156476 MeV** [12].

8.2.7 β- decay from N-16 to O-16

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Nitrogen-16	2	7.13 s	4.02	17.06	117.980736		110.939613	
Oxygen-16	0	Stable	3.55	11.71	127.619296	9.638560	121.360520	10.420907

Decay energy: **10.4209 MeV** [12].

8.2.8 β- decay from O-19 to F-19

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Oxygen-19	+3/+1 PEP gap	26.470 s	4.06499	14.8086	143.763405		135.157588	
Fluorine-19	+1/+1 Req.	Stable	4.06499	14.8086	147.801342	4.037937	139.977872	4.820284

Decay energy: **4.8203 MeV** [12]

8.2.9 β- decay from F-20 to Ne-20

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Fluorine-20	+2/+1 Req.	11.163 s	4.06499	14.0681	154.402680		145.796863	
Neon-20	0	Stable	4.02432	13.6501	160.644800	6.242120	152.821330	7.024467

Decay energy: **7.02447 MeV** [12].

8.2.10 β- decay from Ne-23 to Na-23

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Neon-23	3	37.140 s	4.72159	19.1702	182.970888		172.800377	
Sodium-23	+1/+1 Req.	Stable	4.15764	13.6838	186.564339	3.593451	177.176175	4.375798

Decay energy: **4.37581 MeV** [12].

8.2.11 β- decay from Na-24 to Mg-24

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Sodium-24	+2/+1 Req.	14.96 h	4.71727	18.3210	193.523712		183.353201	
Magnesium-24	0	Stable	4.15616	12.5301	198.257016	4.733304	188.868852	5.515651

Decay energy: **5.515677 MeV** [12].

8.2.12 β- decay from Mg-27 to Al-27

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Magnesium-27	3	9.435 min	4.91315	18.3995	223.124004		211.388799	
Aluminum-27	+1/+1 Req.	Stable	4.77620	16.9034	224.951931	1.827927	213.999073	2.610274

Decay energy: **2.61027 MeV** [12].

8.2.13 β- decay from Al-28 to Si-28

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Aluminum-28	+2/+1 Req.	2.245 min	4.83036	16.8605	232.677032		220.941827	
Silicon-28	0	Stable	4.97732	18.4466	236.536832	3.859800	225.583974	4.642147

Decay energy: **4.64208 MeV** [12].

8.2.14 β- decay from Si-31 to P-31

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Silicon-31	+3/+1 Req.	2.62 h	5.38291	21.0755	262.207021		248.907122	
Phosphorus-31	1	Stable	5.06925	17.6018	262.916177	0.709156	250.398625	1.491503

Decay energy: **1.49151 MeV** [12].

8.2.15 β- decay from P-32 to S-32

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Phosphorus-32	2	14.28 d	5.37951	20.3782	270.851840		257.551941	
Sulfur-32	+1 Req.	Stable	5.36431	20.2061	271.780128	0.928288	259.262576	1.710635

Decay energy: **1.71066 MeV** [12].

8.2.16 β- decay from S-35 to Cl-35

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Sulfur-35	+2/+1 PEP gap/ +1 Req.	87.37 d	5.51502	20.0752	298.824750		283.960157	
Chlorine-35	+1/+1 Req.	Stable	5.36431	18.4741	298.209730	**-0.615020**	284.127484	0.167327

Decay energy: **0.167322 MeV** [12].

8.2.17 β- decay from Cl-36 to Ar-36

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Chlorine-36	+2/+1 Req.	3.013×105 y	5.37909	18.1097	306.789516		291.924923	
Argon-36	0	Stable	5.51502	19.5176	306.716724	**-0.072792**	292.634478	0.709555

Decay energy: **0.70953 MeV** [12].

8.2.18 β- decay from S-37 to Cl-37

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Sulfur-37	+4/+1 PEP gap/ +1 Req.	5.05 min	6.06738	25.2866	313.017595		296.588308	
Chlorine-37	+3/+1 Req.	Stable	5.73346	21.3372	317.100397	4.082802	301.453457	4.865149

Decay energy: **4.86513 MeV** [12].

8.2.19 β- decay from Cl-38 to Ar-38

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Chlorine-38	+4/+1 Req.	37.24 min	5.73346	20.7757	323.208278		306.778991	
Argon-38	2	Stable	5.51502	18.4904	327.342640	4.134362	311.695700	4.916709

Decay energy: **4.91671 MeV** [12].

8.2.20 β- decay from Ar-39 to K-39

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Argon-39	3	269 y	5.62180	19.0831	333.941322		317.512035	
Potassium-39	1	Stable	5.52028	18.0679	333.723975	**-0.217347**	318.077035	0.565000

Decay energy: **0.565 MeV** [12].

8.2.21 β- decay from K-40 to Ca-40

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Potassium-40	2	1.248 × 109 y	5.82057	20.6502	341.523600		325.094313	
Calcium-40	0	Stable	5.49786	17.4025	342.052120	0.528520	326.405180	1.310867

Decay energy: **1.31089 MeV** [12].

8.2.22 β+ decay from F-18 to O-18

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Fluorine-18	0	109.739 min	4.02432	15.1668	137.369484		130.328361	
Oxygen-18	2	Stable	4.06499	15.6313	139.807746	2.438262	131.984276	1.655915

Decay energy: **1.6559 MeV** [12].

8.2.23 β+ decay from Na-22 to Ne-22

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Sodium-22	0	2.602 y	4.15764	13.6838	174.144674		165.538857	
Neon-22	2	Stable	4.07698	12.9027	177.770230	3.625556	168.382066	2.843209

Decay energy: **2.84333 MeV** [12].

8.2.24 β+ decay from Cl-36 to S-36

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Chlorine-36	+2/+1 Req.	3.013 × 105 y	5.37909	18.1097	306.789516		291.924923	
Sulfur-36	+3/+1 PEP gap/ +1 Req.	Stable	6.06738	25.9890	308.714004	1.924488	293.067064	1.142141

Decay energy: **1.14213 MeV** [12].

8.2.25 β+ decay from K-40 to Ar-40

Isotope	Additional PEPs	Half-life	MBS radius	MBS vol./n#	BE (MeV)	Diff BE (MeV)	NMD (MeV)	Diff NMD (MeV)
Potassium-40	2	1.248 × 109 y	5.820570	20.650200	341.523600		325.094313	
Argon-40	4	Stable	5.624830	18.636200	343.810360	2.286760	326.598726	1.504413

Decay energy: **1.50440 MeV** [12].