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# PERIODICITY IN NUCLEAR PROPERTIES

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## Abstract

*This paper includes the findings of empirical research and the development of a scientific instrument. In the line of stable isotopes of an element, the heaviest stable isotope (with even numbers of Z and N) possesses the maximum number of neutrons (the N/Z ratio remains high). The present research work includes such nuclides of elements and the longest-lived isotopes in the case of polonium and heavier elements. The two nearest elements are taken, and the difference of Mass numbers of nuclides is determined. From calcium to uranium, such values are recorded. As a result of this empirical research, the remarkable deviations are found near the electron magic numbers (36, 54 and 86) and the proton magic numbers (50 and 82). Near each electron magic number, a sharp decline in the value is seen.*

*On the basis of empirical findings, an instrument (SCALE) is developed to measure the nuclear properties. This paper includes the development of this instrument and the measured or predicted values. The numerical values (produced by this tool) remain very close to the actual values (the maximum difference remains around 4%). This instrument (SCALE) can be used to read the pattern of nuclear stability.*

**Key Words:** *Element's heaviest stable isotope, even numbers of Z and N, difference of mass numbers, magic numbers, zone of stable/long-lived nuclides, nuclear stability, instrument, nuclear properties*

## Introduction

See the following rough chart and notice the line of beta stability;

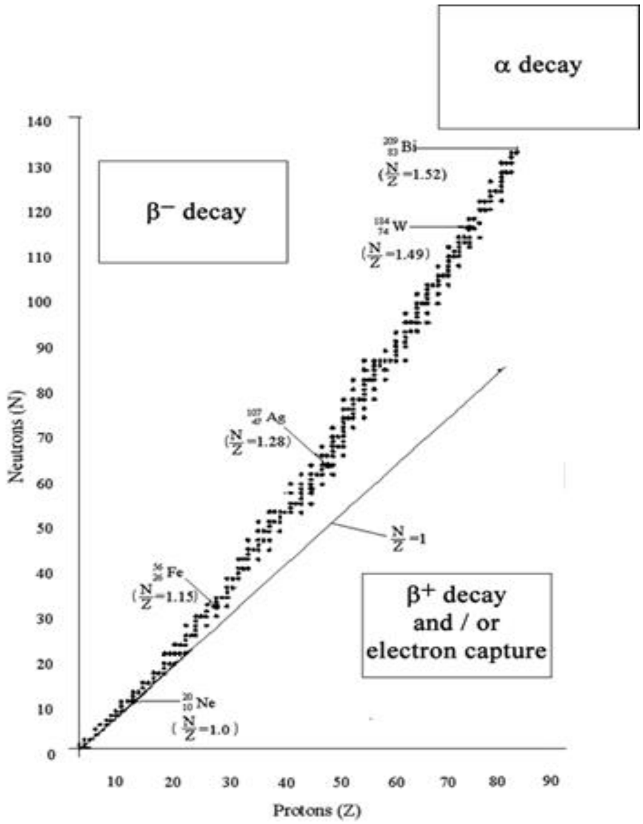



Figure 1

For the light element (with even atomic number), there exists a stable nuclide with the value of N/Z ratio 1 (one). Up to calcium (Z = 20), such case is noticed. Beryllium remains the exception. But in the case of heavier elements, the N/Z ratio becomes higher and the line gets curved.

The above chart depicts that the number of neutrons per proton does not increase systematically after calcium. But the outcome of present empirical research shows that the number of neutrons increases in a systematic way in the case of elements' heaviest stable nuclides (with even numbers of Z and N). From calcium to uranium, the trend remains almost same if the case of the electron magic numbers (36, 54 and 86) and the proton magic numbers (50 and 82) is not included. Near such magic number, the sharp rise or sharp decline in the number of neutrons is noticed.

This paper includes three parts of the work – i) The Empirical Research and Findings, ii) Comparison and Assessment, and iii) The Development of SCALE.

**i) The Empirical Research and Findings**

**1.** Take the following nuclides of the elements (from calcium to uranium)[1, 2];

$^{46}$Ca , $^{50}$Ti , $^{54}$Cr , $^{58}$Fe , $^{64}$Ni , $^{70}$Zn , $^{74}$Ge , $^{80}$Se , $^{86}$Kr , $^{88}$Sr , $^{94}$Zr , $^{98}$Mo , $^{104}$Ru , $^{110}$Pd , $^{114}$Cd , $^{124}$Sn , $^{126}$Te , $^{134}$Xe , $^{138}$Ba , $^{142}$Ce , $^{148}$Nd , $^{154}$Sm , $^{160}$Gd , $^{164}$Dy , $^{170}$Er , $^{176}$Yb , $^{180}$Hf , $^{186}$W , $^{192}$Os , $^{198}$Pt , $^{204}$Hg , $^{208}$Pb , $^{209}$Po , $^{222}$Rn , $^{226}$Ra , $^{232}$Th , $^{238}$U.

**2.** These are the heaviest stable nuclides of the elements. In the case of elements which have Atomic number (Z) greater than 82, the longest-lived isotopes are considered.

**3.** Such nuclides have even numbers of Z and N (except $^{209}$Po). The nuclides which have even numbers of Z and N remain more stable. In the line of stable nuclides of the element, the heaviest stable nuclide possesses the maximum number of neutrons (the N/Z ratio remains high).

**4.** Now, determine the difference of Atomic numbers (ΔZ) of the nearest elements. For example;

$\Delta Z = {}_{22}Ti - {}_{20}Ca = 2$ ; similarly, $\Delta Z = {}_{24}Cr - {}_{22}Ti = 2$ ; $\Delta Z = {}_{26}Fe - {}_{24}Cr = 2$ ; $\Delta Z = {}_{92}U - {}_{90}Th = 2$ ; and so on.

**5.** Take the Mass number (A) of each nuclide. And then determine the difference of Mass numbers (ΔA), taking the two nearest elements. The two nearest elements form a set. See the following sets;

Δ**A1** = $^{50}$Ti - $^{46}$Ca = **4** ; similarly, Δ**A2** = $^{54}$Cr - $^{50}$Ti = **4** ; Δ**A3** = $^{58}$Fe - $^{54}$Cr = **4** ; Δ**A4** = $^{64}$Ni - $^{58}$Fe = **6** ; Δ**A5** = $^{70}$Zn - $^{64}$Ni = **6** ; Δ**A6** = $^{74}$Ge - $^{70}$Zn = **4** ; Δ**A7**= $^{80}$Se - $^{74}$Ge = **6** ; Δ**A8** = $^{86}$Kr - $^{80}$Se = **6** ; Δ**A9** = $^{88}$Sr - $^{86}$Kr = **2** ; Δ**A10** = $^{94}$Zr - $^{88}$Sr = **6** ; Δ**A11** = $^{98}$Mo - $^{94}$Zr = **4** ; Δ**A12** = $^{104}$Ru - $^{98}$Mo = **6** ; Δ**A13** = $^{110}$Pd - $^{104}$Ru = **6** ; Δ**A14** = $^{114}$Cd - $^{110}$Pd = **4** ; Δ**A15** = $^{124}$Sn - $^{114}$Cd = **10** ; Δ**A16** = $^{126}$Te - $^{124}$Sn = **2** ; Δ**A17** = $^{134}$Xe - $^{126}$Te = **8** ; Δ**A18** = $^{138}$Ba - $^{134}$Xe = **4** ; Δ**A19** = $^{142}$Ce - $^{138}$Ba = **4** ; Δ**A20** =$^{148}$Nd - $^{142}$Ce = **6** ; Δ**A21** = $^{154}$Sm - $^{148}$Nd = **6** ; Δ**A22** = $^{160}$Gd - $^{154}$Sm = **6** ; Δ**A23** = $^{164}$Dy - $^{160}$Gd = **4** ; Δ**A24** = $^{170}$Er - $^{164}$Dy = **6** ; Δ**A25** = $^{176}$Yb - $^{170}$Er = **6** ; Δ**A26** = $^{180}$Hf - $^{176}$Yb = **4** ; Δ**A27** = $^{186}$W - $^{180}$Hf = **6** ; Δ**A28** = $^{192}$Os - $^{186}$W = **6** ; Δ**A29** = $^{198}$Pt - $^{192}$Os = **6** ; Δ**A30** = $^{204}$Hg - $^{198}$Pt = **6** ; Δ**A31** = $^{208}$Pb - $^{204}$Hg = **4** ; Δ**A32** = $^{209}$Po - $^{208}$Pb = **1** ; Δ**A33** = $^{222}$Rn - $^{209}$Po = **13** ; Δ**A34** = $^{226}$Ra - $^{222}$Rn = **4** ; Δ**A35** = $^{232}$Th - $^{226}$Ra = **6** ; Δ**A36** = $^{238}$U - $^{232}$Th = **6** .

**6. Now, make a chart taking the values of ΔA.**

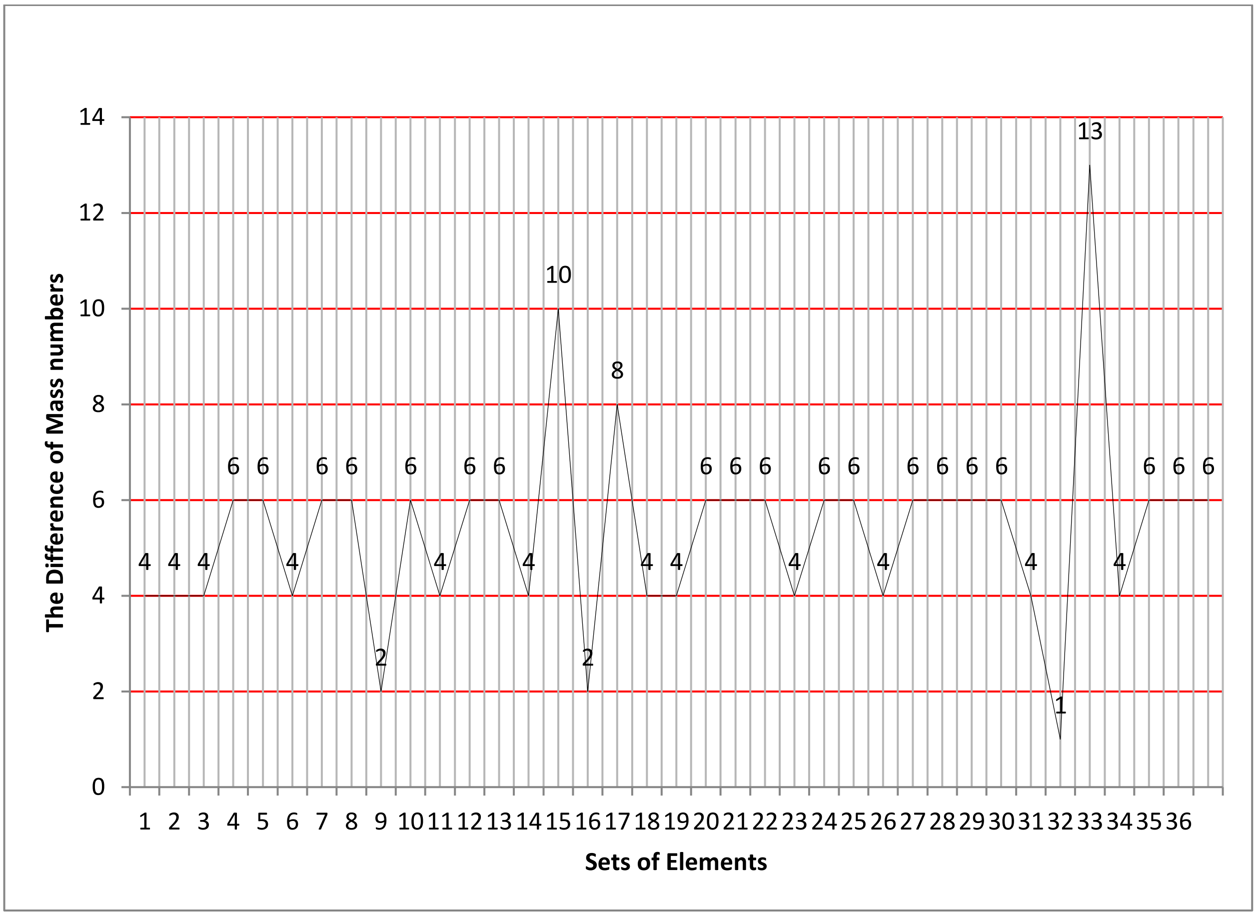



**Figure 2**

**7. See the chart carefully. Near the electron magic numbers (36, 54 and 86)[3, 4] and the proton magic numbers (50 and 82)[3], the remarkable deviations are achieved. Near each electron magic number, a sharp decline or sharp rise in the value can be seen**.

**Take the most frequent and higher value of ΔA. This is found 6. Determine the value of ΔA/ΔZ ratio. Such value remains 3.0.** As per the chart, the values 10, 8 and 13 seem infrequent and exceptional.

**8.** Notice the elements Kr (involved in set ΔA9), Xe (involved in sets ΔA17and ΔA18) and Rn (involved in sets ΔA33 and ΔA34). These elements show the higher value of A/ Z ratio.

Kr (Z = 36), Xe (Z = 54), and Rn (Z = 86) depict the electron magic numbers.

$^{46}$Ca , $^{50}$Ti , $^{54}$Cr , $^{58}$Fe , $^{64}$Ni , $^{70}$Zn , $^{74}$Ge , $^{80}$Se , $^{86}$**Kr** , $^{88}$Sr, $^{94}$Zr , $^{98}$Mo , $^{104}$Ru , $^{110}$Pd , $^{114}$Cd , $^{124}$Sn , $^{126}$Te , $^{134}$**Xe** , $^{138}$Ba , $^{142}$Ce , $^{148}$Nd , $^{154}$Sm , $^{160}$Gd , $^{164}$Dy , $^{170}$Er , $^{176}$Yb , $^{180}$Hf , $^{186}$W , $^{192}$Os , $^{198}$Pt , $^{204}$Hg , $^{208}$Pb , $^{209}$Po , $^{222}$**Rn** , $^{226}$Ra , $^{232}$Th , $^{238}$U.

**Near each electron magic number, a sharp decline or sharp rise in the value is seen**. Take the elements found before and after such magic number. These form the two groups. Identify and form such other groups. See these;

$^{50}$Ti, $^{54}$Cr, $^{58}$Fe, $^{64}$Ni, $^{70}$Zn, $^{74}$Ge, $^{80}$Se – **Group 1**; $^{94}$Zr, $^{98}$Mo, $^{104}$Ru, $^{110}$Pd, $^{114}$Cd – **Group 2**; $^{138}$Ba, $^{142}$Ce, $^{148}$Nd, $^{154}$Sm, $^{160}$Gd, $^{164}$Dy, $^{170}$Er, $^{176}$Yb, $^{180}$Hf, $^{186}$W, $^{192}$Os, $^{198}$Pt, $^{204}$Hg, $^{208}$Pb - **Group 3**; $^{226}$Ra, $^{232}$Th, $^{238}$U - **Group 4**.

**9**. Now in the case of each element, determine the value of A/ Z ratio.

**10. Take the elements of each group and make the chart with the help of their A/ Z values.**

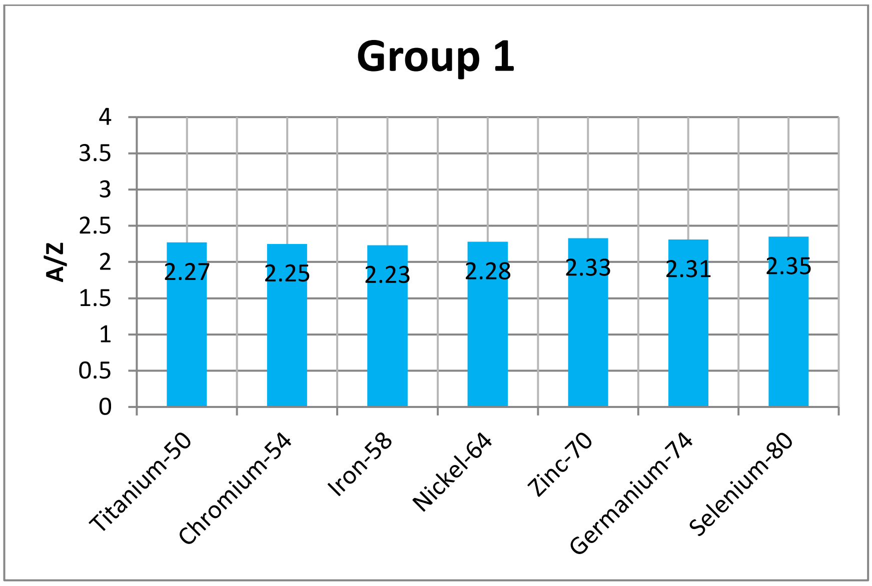



Figure 3

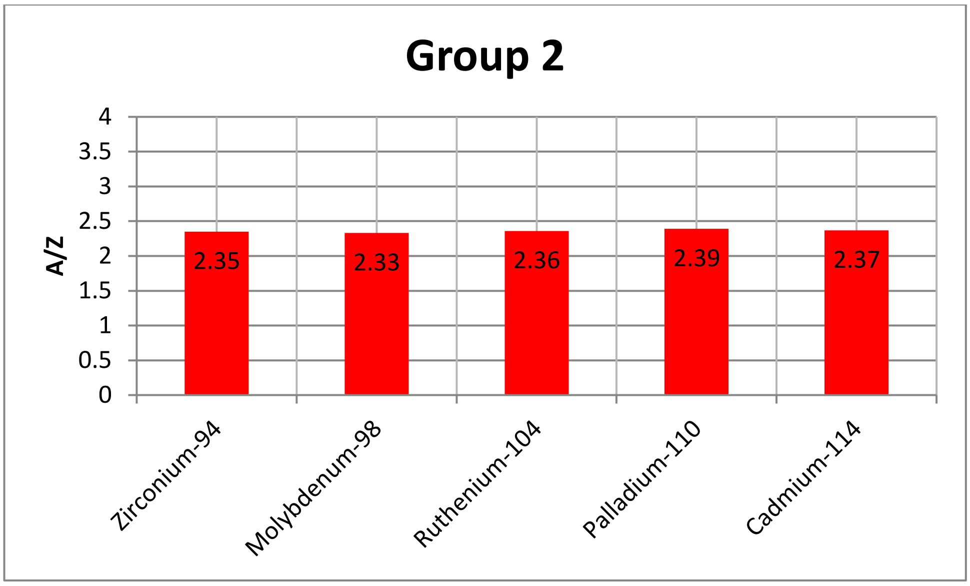



Figure 4

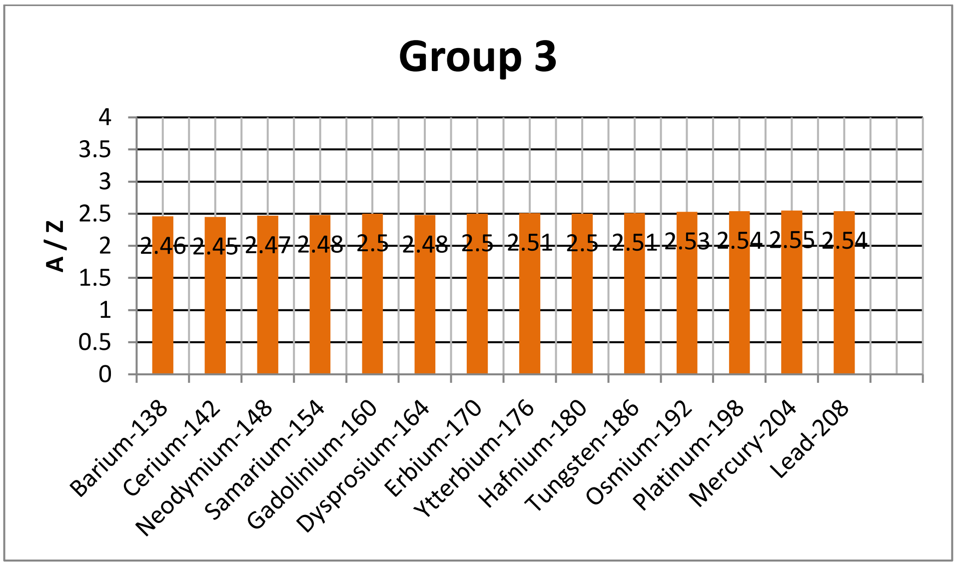



Figure 5

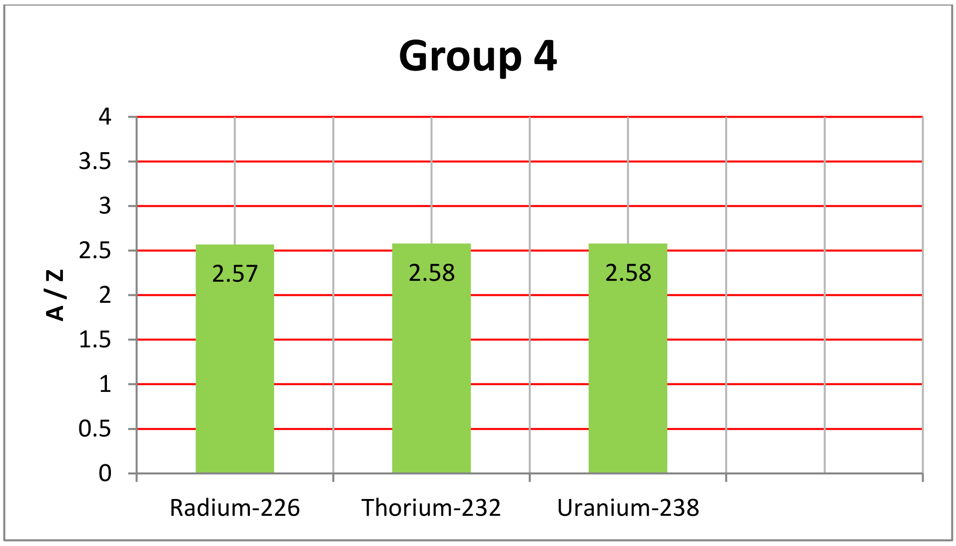



Figure 6

**11. From each group, take the element which remains near the average value of A/ Z ratio. The elements Ni, Ru, Yb and U can be taken.**

**12.** See the Point number 5. In the set of elements, the maximum number of nucleons increased from one element to another element remains 6 normally (if we don't include the case of Magic Numbers). The maximum number of neutrons increased from one element to another element remains 4.

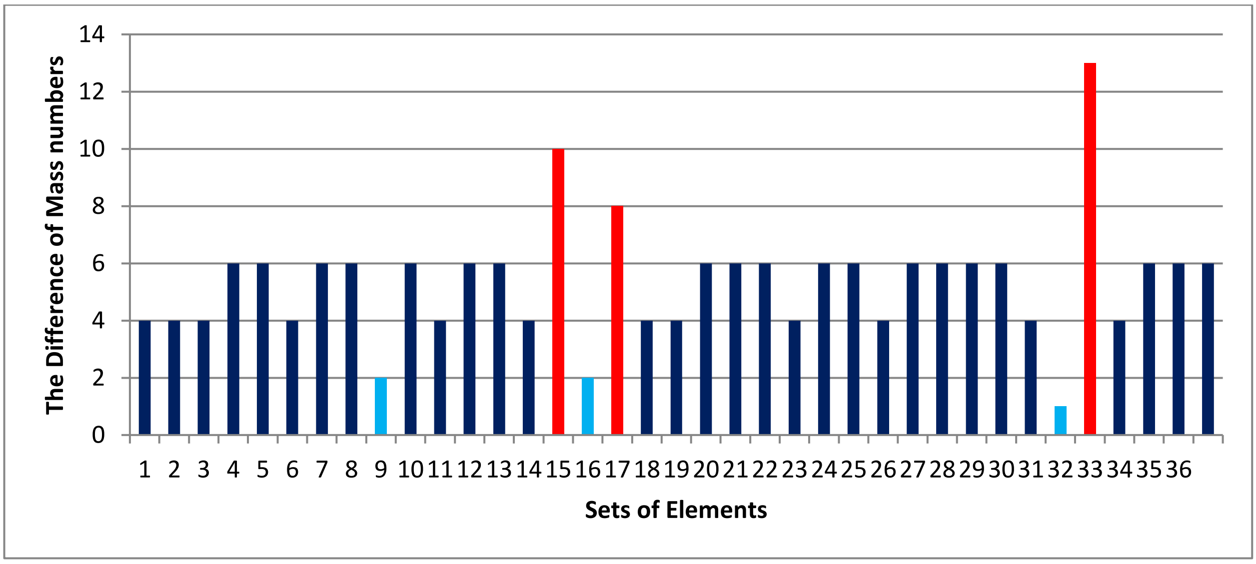



Figure 7

The most frequent and higher value of ΔA is found 6. The value of ΔA/ΔZ ratio remains 3.0. Now to make a comparison, draw the bar chart taking element's A/ Z value and the already determined ΔA/ΔZ value.

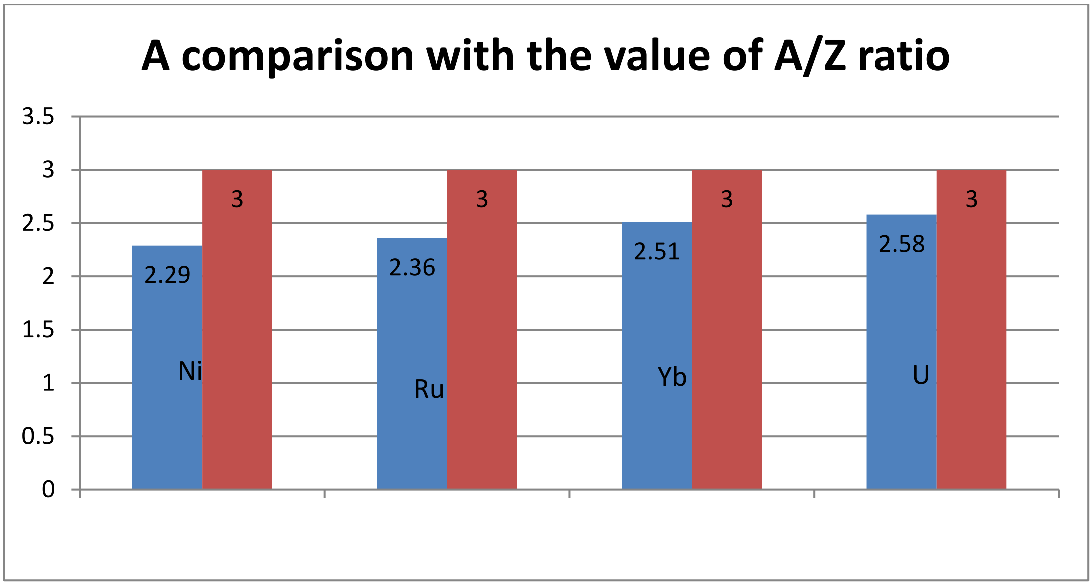



**Figure 8**

**13. Now, think about the nuclide found near the one-neutron dripline.** As per the empirical evidence/ experimental data [5, 6], the neutron rich isotopes found just before the first unbound nuclides or very short-lived radioactive nuclides of the elements (from oxygen onwards) generally show the values of A/Z ratio between **3** and 3.2. We can see that the value of such ratio does not remain **4** or **5**. It does not remain even **3.5 or 2.75**.

| Z | A | A/Z |
|---|---|---|
| 8 | 24 (i.e., 3Z + 0) | 3.0 |
| 9 | 27 (i.e., 3Z + 0) | 3.0 |
| 10 | 32 (i.e., 3Z + 2) | 3.2 |
| 11 | 35 (i.e., 3Z + 2) | 3.18 |
| 12 | 38 (i.e., 3Z + 2) | 3.17 |
| 15 | 47 (i.e., 3Z + 2) | 3.13 |
| 16 | 50 (i.e., 3Z + 2) | 3.12 |
| 17 | 53 (i.e., 3Z + 2) | 3.12 |
| 18 | 56 (i.e., 3Z + 2) | 3.11 |
| 19 | 57 (i.e., 3Z + 0) | 3.0 |
| 20 | 60 (i.e., 3Z + 0) | 3.0 |

Now seeing the trend, take an isotope of nickel which shows A/Z value close to the value of ΔA/ΔZ ratio (i.e., 3.0) already determined (see the Point number 12 and the Figure 8). And then compare it with the heaviest stable isotope of nickel (i.e., nickel-64) which remains near the average value of A/Z ratio (see Figure 8 and Figure 3).

It is found that nickel-84 remains near the ΔA/ΔZ ratio. The value of A of nickel-84 remains equal to 3Z.

Now, make a bar chart taking the values of mass[7] of such isotopes, or the equivalent values of mass.

(Nuclear mass = 0.9997 x Atomic mass)

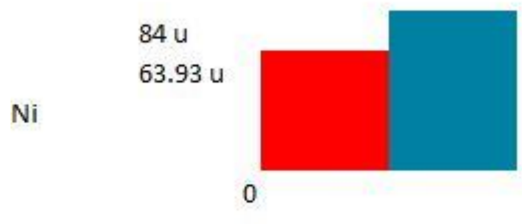



**Figure 9**

**14.** Similarly in the case of Ru, such isotopes will be ruthenium-132 and ruthenium-104.

Now, make a bar chart taking the values of mass[7] of such isotopes, or the equivalent values of mass:

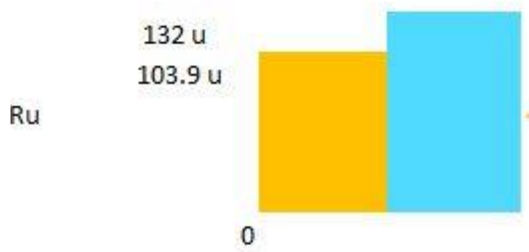



**Figure 10**

In the case of Yb, such isotopes will be ytterbium-210 and ytterbium-176.

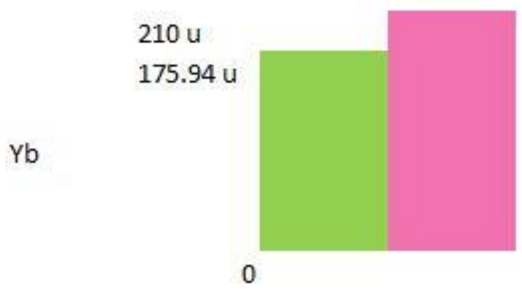



Figure 11

In the case of U, such isotopes will be uranium-276 and uranium-238.

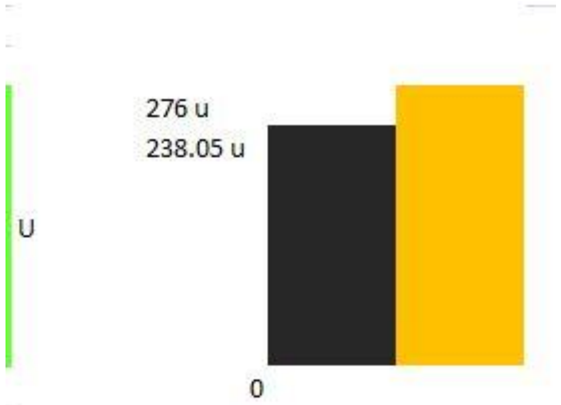



Figure 12

The value of mass depicted by the small bar remains near the value of mass[7] of the heaviest stable isotope or the longest-lived isotope of the element, whereas the value of mass depicted by the big bar gives a remarkable result. The isotope bearing such value of mass remains near the one-neutron dripline ($S_n = 0$) of this element, or near the isotope of very short half-life.

**15. Now, use the various sheets to make the chart for each element. Try different sheets as much as possible. One of those sheets shows the following chart. If a box is covered in the case of such element, it is found that the length of small bar becomes almost equal to the length of uncovered part of big bar. The number of total boxes remains equal to the number of energy levels [3, 4] of the element. In the case of Ni, one of the four boxes is covered.**


Figure 13

One of those sheets shows the following chart for ruthenium. In the case of Ru, one of the five boxes is covered.

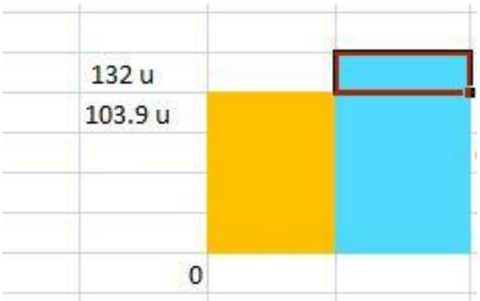



Figure 14

The other sheets show the following charts for ytterbium and uranium. In the case of Yb, one of the six boxes is covered. In the case of U, one of the seven boxes is covered.


Figure 15

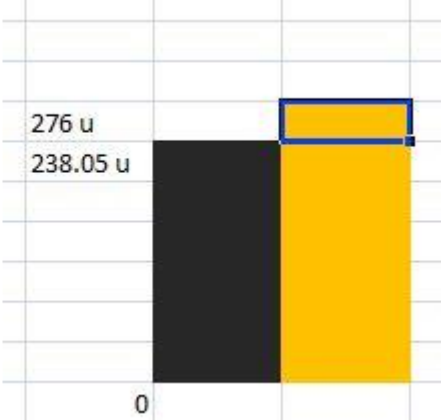



Figure 16

If a box is covered in the case of each element, it is found that the length of small bar becomes almost equal to the length of uncovered part of big bar. The number of total boxes remains equal to the number of energy levels [3, 4] of the element.

**16.** Now, take a value of mass equivalent to the mass of total number of protons of such element. In the case of nickel element (Ni), this value of mass remains about 28.204 u (i.e., 28 x 1.00727646 u).

**17. Make a bar chart, taking such equivalent value of mass.** The length of the bar must be equal to the length of already drawn big bar showing the value of mass of heavier isotope (See the Point number 14 chart).

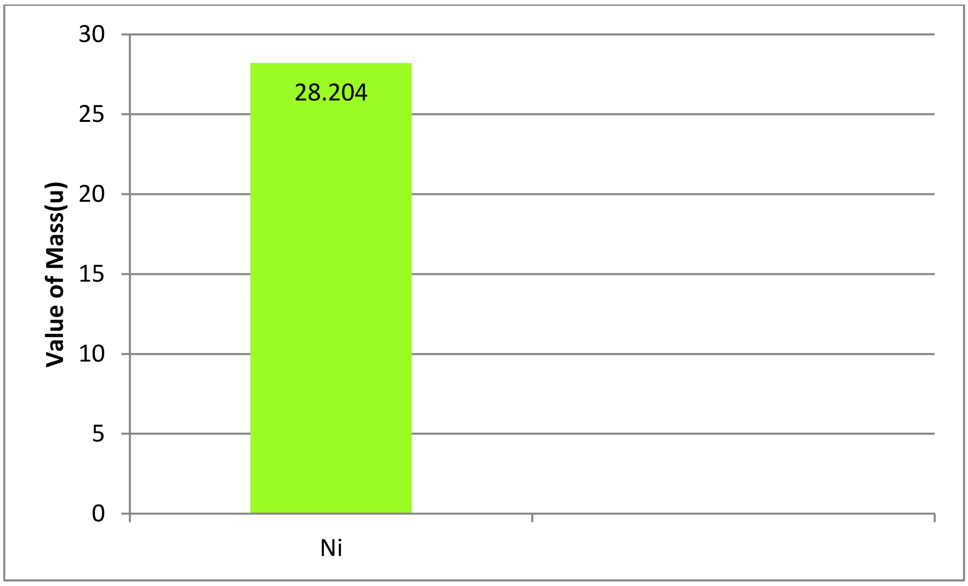



Figure 17

Similarly in the case of other elements, the bar charts look like:

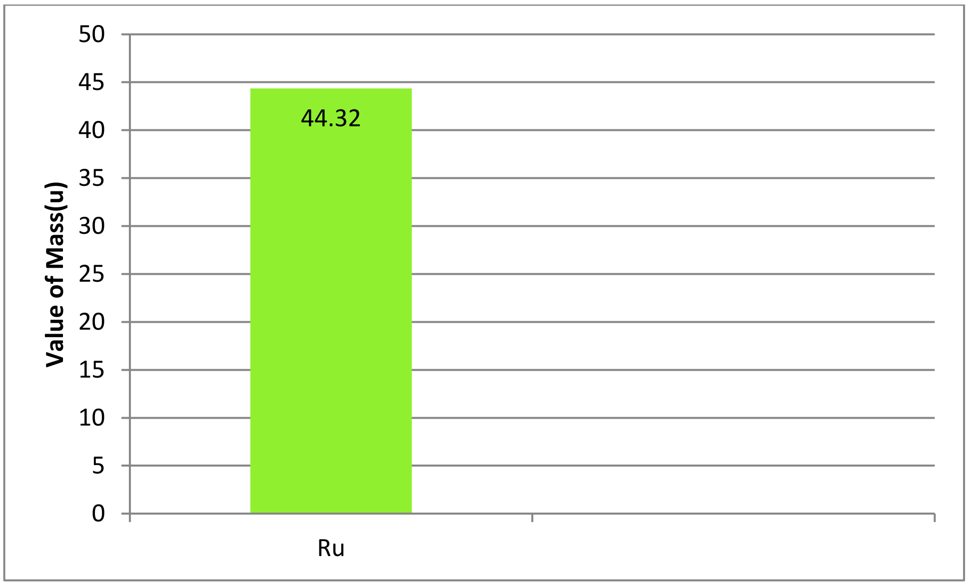



Figure 18

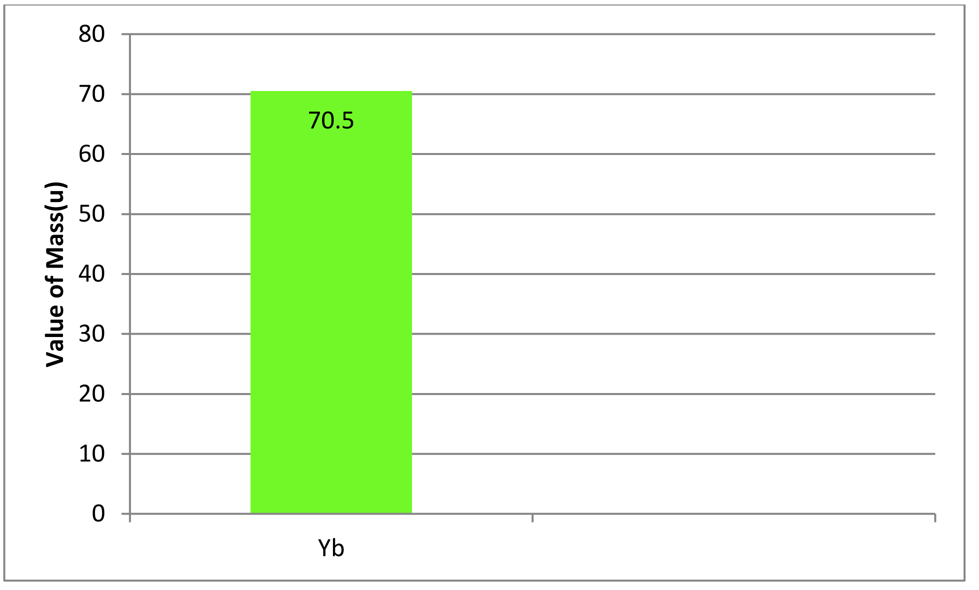



Figure 19

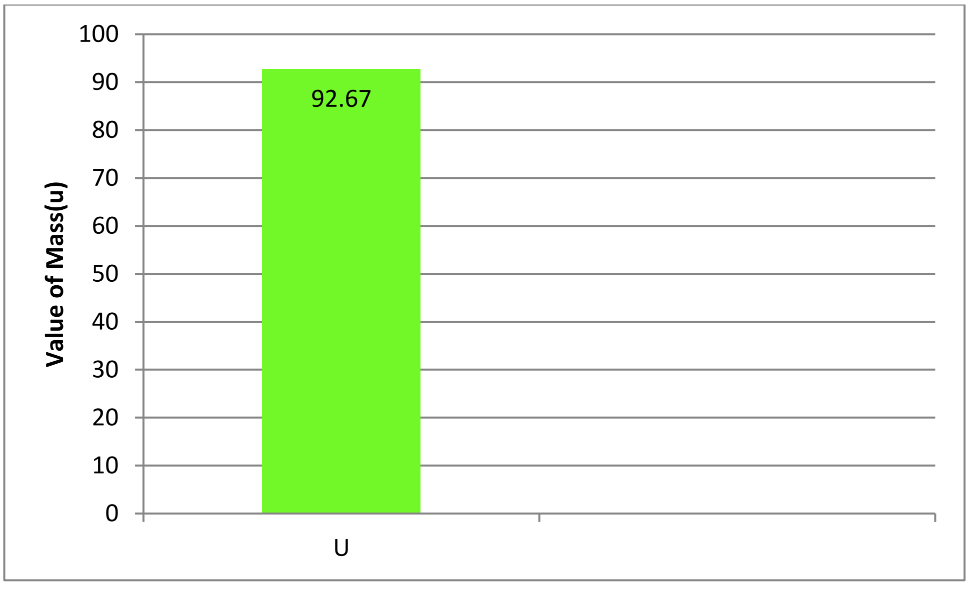



Figure 20

**18.** Now for making a comparison, bring such bar chart near the already drawn bar chart depicting the values of mass of two isotopes of the element (see Point number 15). Keep them as shown;


Figure 21

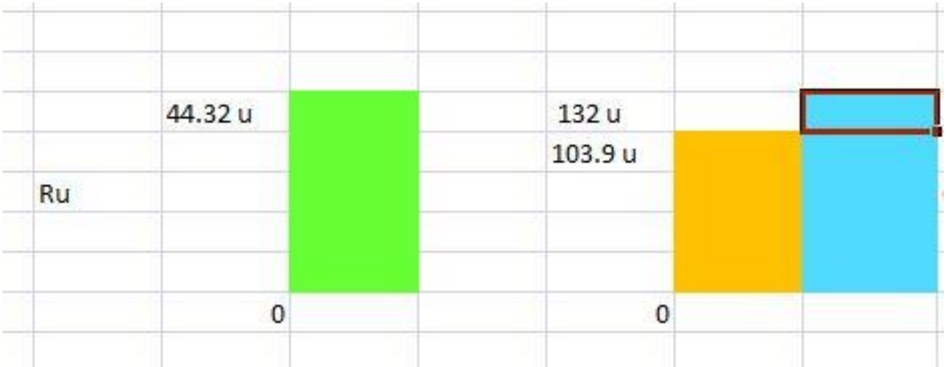



Figure 22


Figure 23

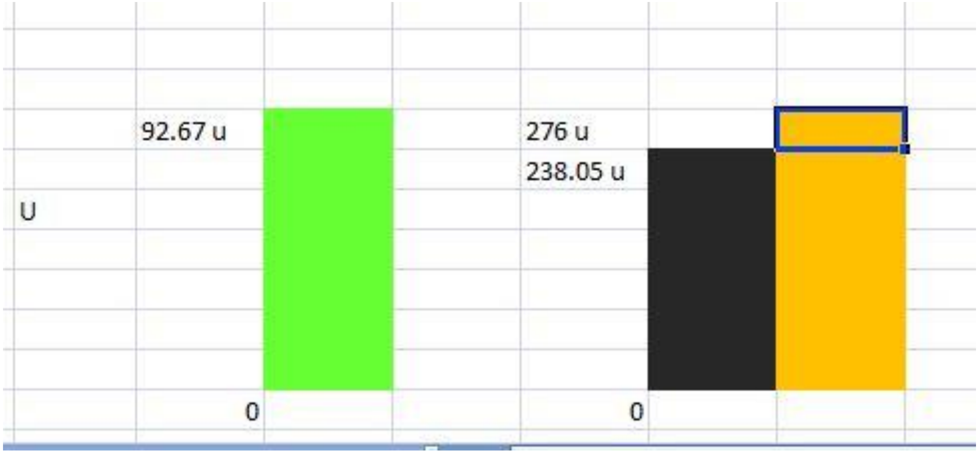



Figure 24

**19.** Such findings spark an idea to develop a **SCALE**[8] for making comparison, assessing the stable or long-lived nuclides of the elements, and measuring the differences.

**ii) Comparison and Assessment**

**20.** Now take a Group's all those elements, which have stable nuclide(s). Then make a chart with the help of A/Z value(s) of an element's stable isotope(s). See the following chart as an example;

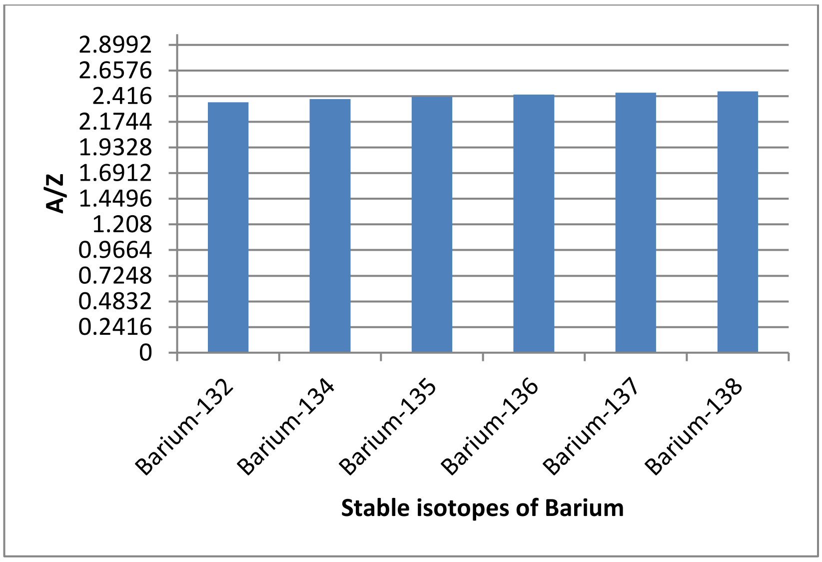



Figure 25

See the above chart and notice the barium's stable isotope which remains near the average value of A/ Z ratio. The isotope $^{135}$Ba can be taken.

**21.** Now from each element, take an isotope which remains near the average value of A/ Z ratio. Then, make a chart with the help of their measured A/Z values.

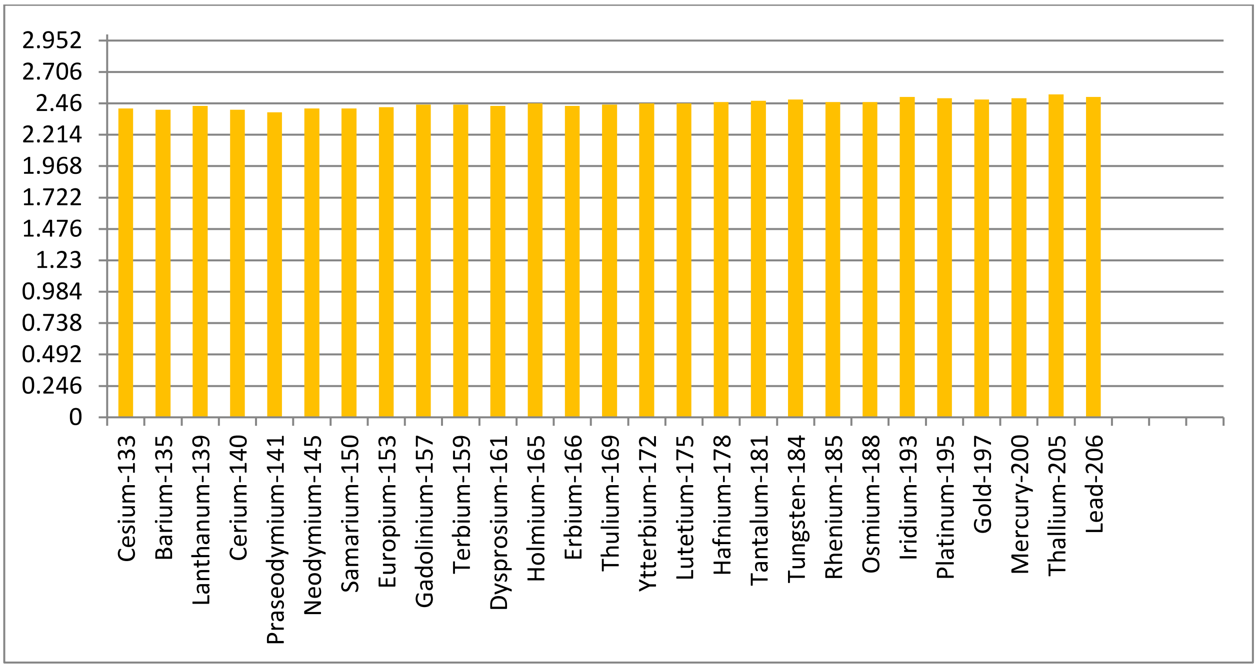



**Figure 26**

Make the chart in the case of each Group. See these;

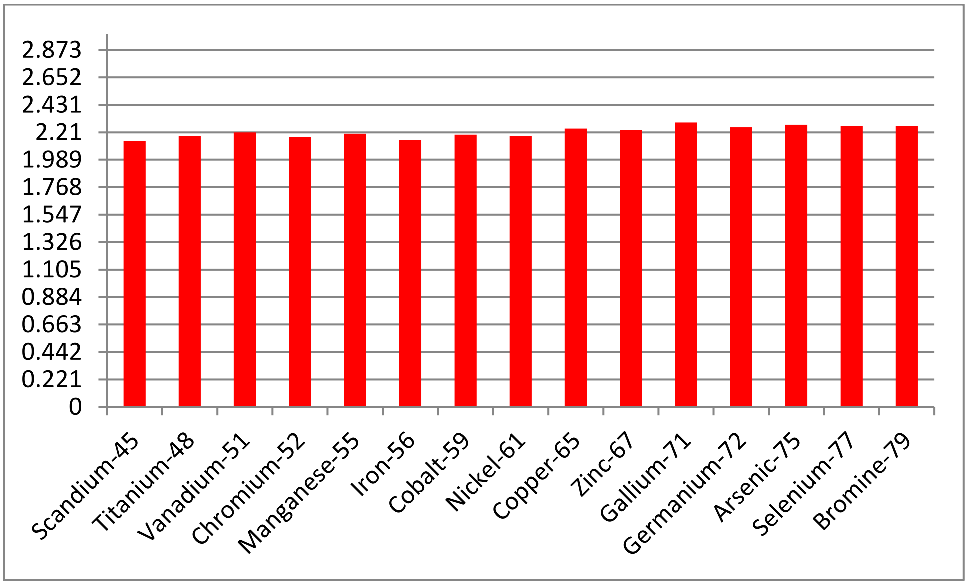



**Figure 27**

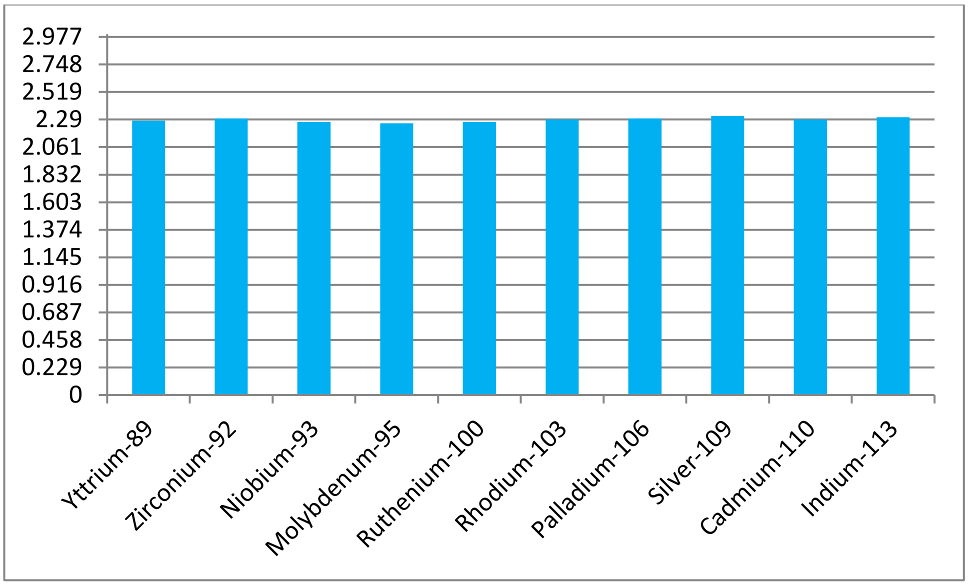



Figure 28

**22.** From each Group, take an element's isotope which remains near the average value of A/ Z ratio. The isotopes $^{51}V$, $^{103}Rh$, and $^{165}Ho$ can be taken from these groups.

**23.** Now, notice the following figure already drawn in the case of nickel (Ni). Then, take an element of the same Group. For example, take vanadium (V).


Figure 29

Take the mass[7] of $^{51}V$, or the equivalent value of mass. And draw a bar chart as shown;

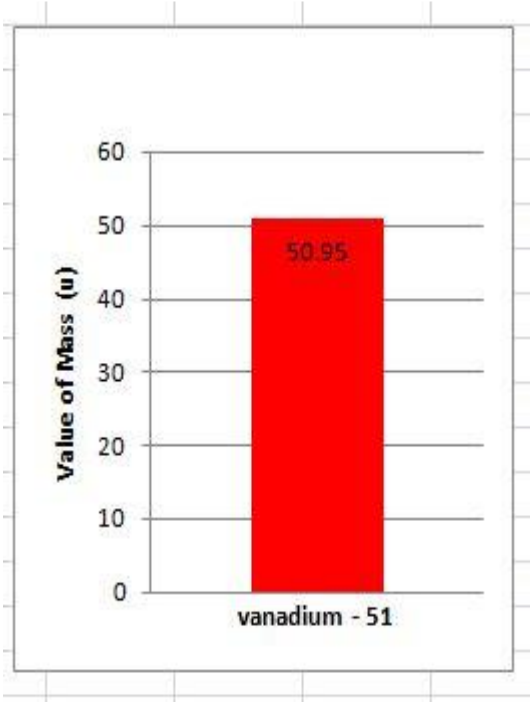



Figure 30

Then, take a value of mass equivalent to the mass of total number of protons of vanadium and draw a chart. This is to be known as 'Bar Diagram 1'.

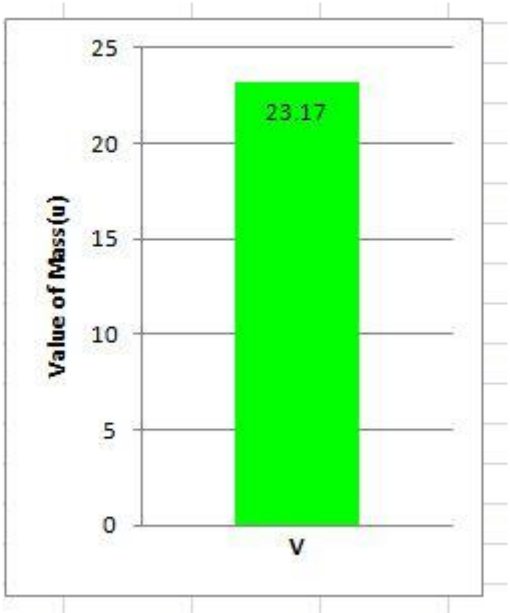



Figure 31

Draw a bar chart of unknown value of mass. This is to be known as 'Bar Diagram 2'.

Figure 32

**24.** Now, manage the size and position of these three bar diagrams as per the figure drawn in the case of nickel. See the Figure 21. In the case of V, the figure looks like as;

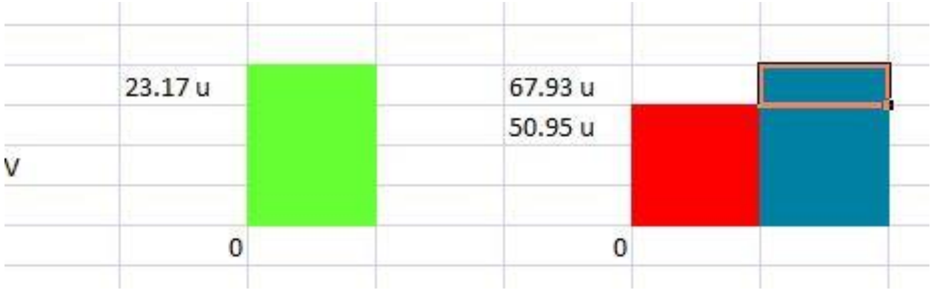



Figure 33

Thus, we get the maximum value of mass depicted by the blue bar. It remains 67.93 u. In the case of vanadium, this value remains equal to **2.932** times the value of mass depicted by the light green chart.

**Similarly, we can determine the maximum value of mass depicted by such bar of unknown values.**

In the case of Rh, the figure looks like as;

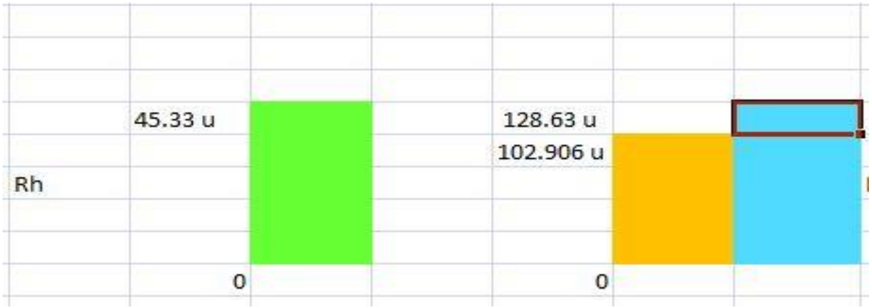



Figure 34

Thus, we get the maximum value of mass depicted by the sky coloured bar. It remains 128.63 u. In the case of Rh, this value remains equal to **2.838** times the value of mass depicted by the light green chart.

Now in the case of Ho, the figure looks like as;

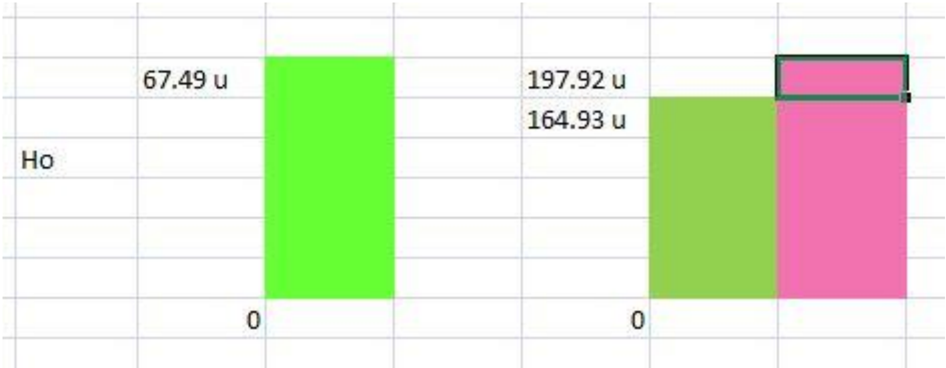



Figure 35

Here, we get the maximum value of mass depicted by the pink bar. It remains 197.92 u. In the case of Ho, this value remains equal to **2.933** times the value of mass depicted by the light green chart.

**In the case of element that does not have stable isotope**[2]

**25.** Make a common bar diagram, which depicts a value of mass equal to **2.91** times the value of mass depicted by the light green chart (i.e. **Bar Diagram 1**). Such bar diagram (to be known as **Bar Diagram 2)** is used for all the elements of groups.

(**2.91** remains the approximate average value of 2.932, 2.838 and 2.933)

**26.** Now with the help of **Bar Diagram 1** and **Bar Diagram 2**, determine the mass of long-lived isotopes of the elements of Group 4 (from Z = 87 onwards).

Manage the size and position of the bar diagrams as per the figure drawn in the case of uranium (U). See the Figure 24. In the case of Pa, the figure looks like as;


**Figure 36**

Thus, we get the value of mass (i.e., 228.63 u) that remains near the Atomic mass[7] of long-lived radioactive isotope of Pa.

Similarly, in the case of Hs, the figure looks like as;


**Figure 37**

We get a value of mass (i.e., 271.34 u) that remains near the Atomic mass[7] of long-lived radioactive isotope of Hs.

**27.** In the case of Lv, we get a value of mass (i.e., 291.44 u) that remains near the Atomic mass[7] of long-lived radioactive isotope of this element. See the following figure,


Figure 38

**iii) The Development of SCALE (an instrument)**

**28.** Now, see the **Bar Diagram 2** common for all the elements of groups;

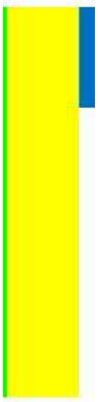


Figure 39

This yellow bar diagram (i.e., **Bar Diagram 2**) depicts a value of mass equal to **2.91** times the value of mass depicted by the light green chart (i.e. **Bar Diagram 1**).

See the following bar diagram (**Bar Diagram 1**) that depicts the value of mass equivalent to the mass of total number of protons of the element;

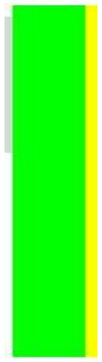


**Figure 40**

This **Bar Diagram 1** depicts different values for the different chemical element. When we choose an element for making comparison, this Bar Diagram 1 depicts a value of mass equivalent to the mass of total protons of this element.

**29.** Now, notice the following figure:


**Figure 41**

See the small black bar in the figure. Such smaller bar diagram has been used to show the mass of stable or long-lived isotope of the element. But now to predict the mass of stable or long-lived isotope of the element, use **Bar Diagram 1** and **Bar Diagram 2** only.

For making comparison, keep them as shown in the following figure;

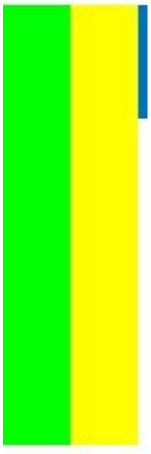


Figure 42

**30.** See the Point number 15.

If a box is covered in the case of each element, it is found that the length of small bar becomes almost equal to the length of uncovered part of big bar. But now instead of such hollow box, use the colored box (to be known as **Multiplier**). See the following figure;

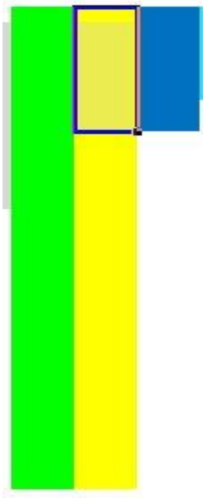


Figure 43

For the different Groups, use the boxes of different colors and sizes. Make a fold of such boxes (Multipliers). See the following figure;

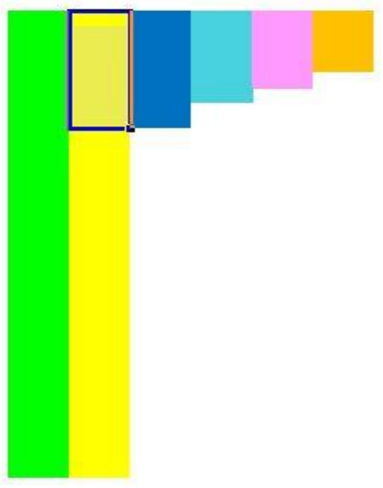


Figure 44

**The Components of SCALE**

**31.** SCALE has two major components:

1) Common Component, and 2) Specific Component.

Common Component includes RA (Representative Area), Fold of Multipliers, Slider, and TNSE side.

Specific Component includes Single Element Card. The Single Element Card is composed of Side A, and CS (Comparative Side).

**1) The Parts of Common Component:-**

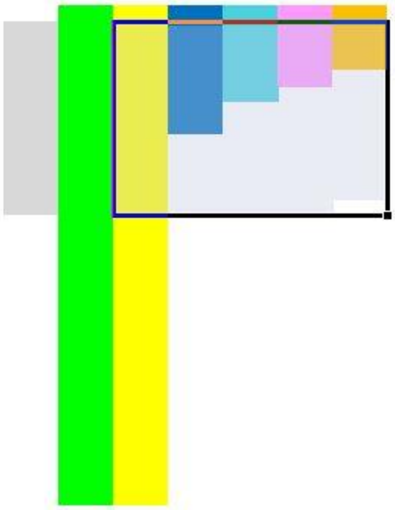


Figure 45

a) Representative  Area (RA) ----

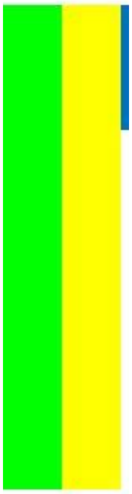
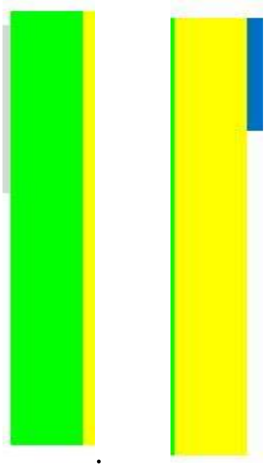


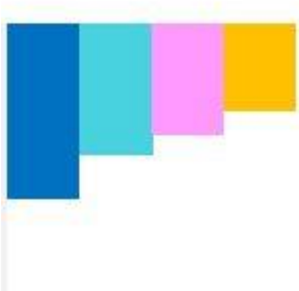
Figure 46

RA is composed of two bar diagrams ------ Bar Diagram 1, and Bar Diagram 2. The length of Bar Diagram 1 remains equal to the length of Bar Diagram 2. See the figures given below;



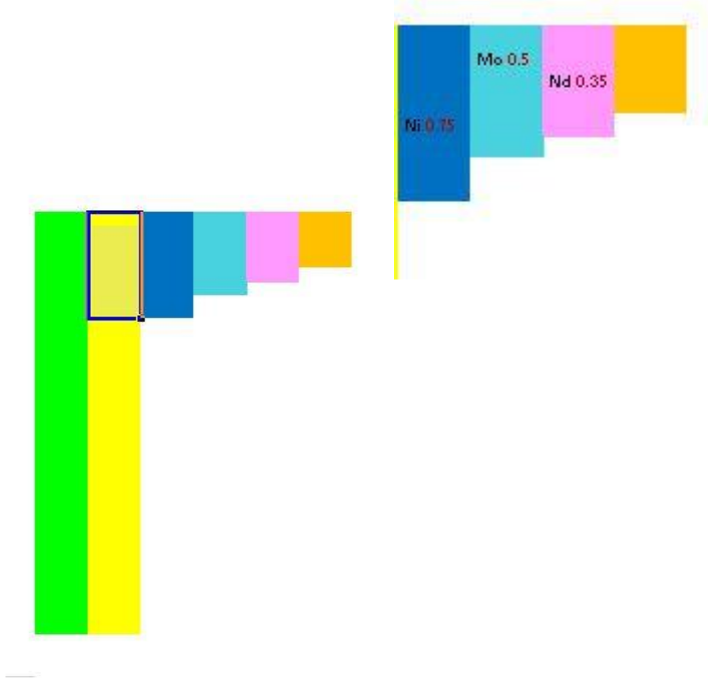
These bar diagrams are used (as the parts of RA) for making comparison.

b) Fold of Multipliers ------



Multiplier shows the symbol of chemical element and the equivalent value. This equivalent value shows that the maximum value of mass (printed on Side A) is how many times the mass of total number of protons of this chemical element (or the equivalent value of mass). See this figure for example;

Figure 47




Fold of Multipliers is used as the part of Common Component. Multiplier depicts that the total area of Bar Diagram 2 remains how many times the area of it.

Take some elements. For example, take Lv, Ac, Db, and Cn. For such elements, the total area of Bar Diagram 2 remains seven times the area of appropriate multiplier.

Take Zn, Mn, Ti, Cu, and Br. For such elements, the total area of Bar Diagram 2 remains four times the area of appropriate multiplier.

In the case of Cd, Zr, Ag, Ru, Mo, etc., the total area of Bar Diagram 2 remains five times the area of appropriate multiplier.

In the case of Ba, Gd, Cs, Lu, Ta, etc., the total area of Bar Diagram 2 remains six times the area of appropriate multiplier.

c) Slider --------

**Figure 48**

Slider is used to mark the values of mass. Slider can move upward or downward.

In the case of a chemical element, apply the Multiplier that shows the symbol of this element. You have to use the appropriate Multiplier to find the results.

As per the position of Multiplier, adjust the Slider to mark the values. See these figures;

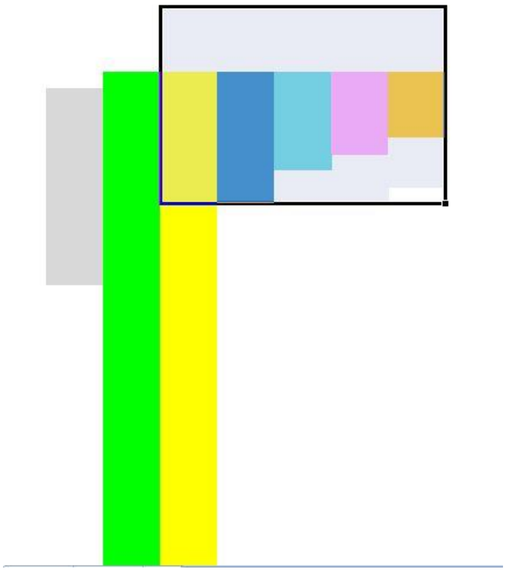


**Figure 49**

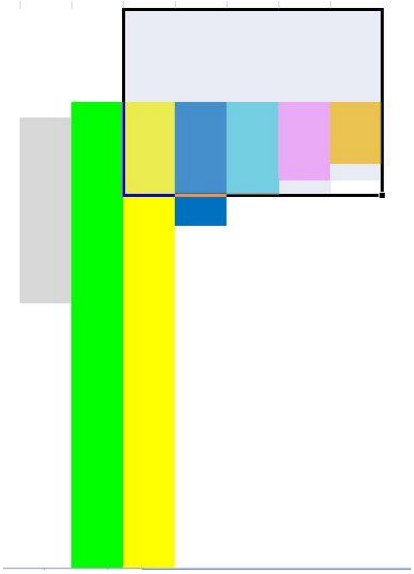


**Figure 50**

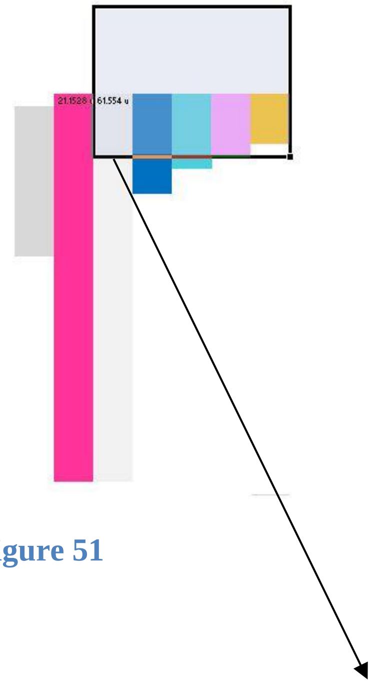



Figure 51

The location very close to the lower side of adjusted Slider depicts the Zone of Stable or Long-lived nuclides of the element.

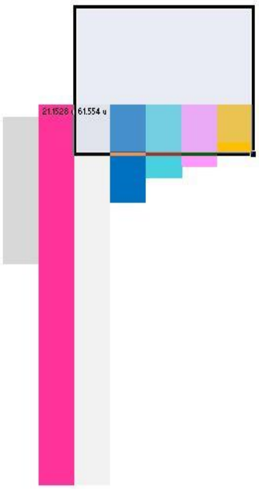



Figure 52

d) TNSE side --------

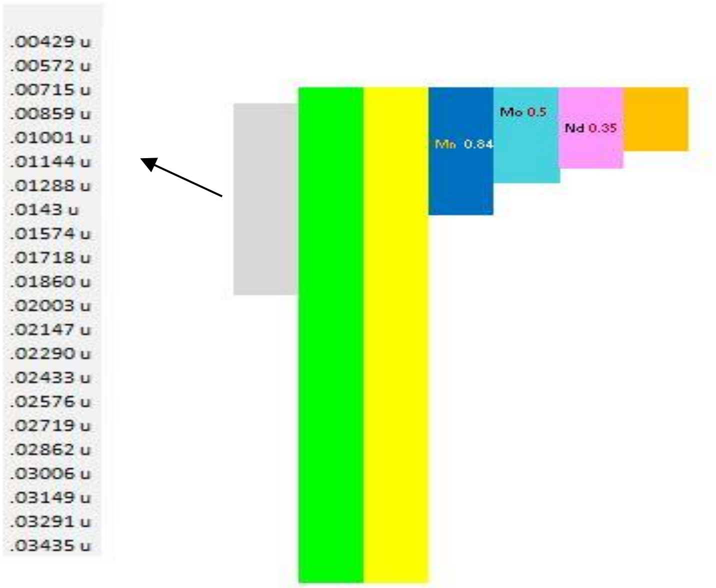



**Figure 53**

This side is added to identify the location of isotope according to the value of two-neutron separation energy. See the above figure.

On TNSE side, the value of mass increases as we go down. The value of mass varies according to the variation in area. On CS, see the location in front of such value of mass. Near this location, remains the isotope related to such value of mass or two-neutron separation energy.

**2) The Parts of Specific Component:-**

Specific Component includes Single Element Card. The Single Element Card is composed of Side A and CS.

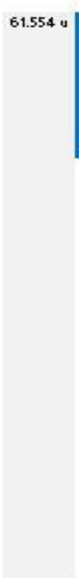

Figure 54

a) Side A -----

Side A depicts a value of mass equivalent to the mass of total protons of scandium element (i.e., 21.1528 u). The maximum value of mass (depicted by Side A) is used to make a comparison.


Figure 55

b) Comparative Side (CS) ------



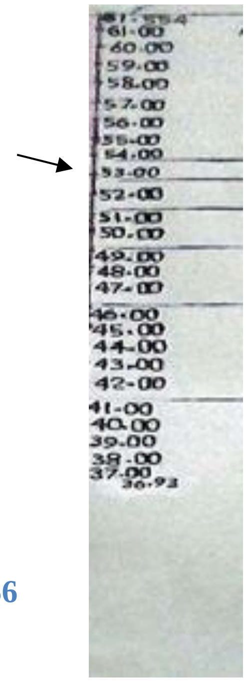




**Figure 56**

The apex of CS shows a value of mass (i.e., 61.554 u). This value of mass remains 2.91 times the value of mass depicted by Side A. On CS, the value of mass decreases as we go down. This happens due to the variation in area. The length of CS remains equal to the length of Side A.

CS is developed to show the mass of stable or long-lived nuclide of the element. The value of mass depicted by the uncovered area of CS (i.e., the lower part which is not covered by the adjusted Slider) remains near the mass of stable or long-lived nuclide of the element.

The part of CS that touches the apex of Side A gives a location, which remains near the One-neutron Dripline ($S_1n= 0$) of this element.

**32.** Now see the following figure;

Side A (i.e., the part of Single Element Card) is attached to the Bar Diagram 1 of RA.

CS (i.e., the other part of Single Element Card) is attached to the Bar Diagram 2 of RA.

We see that the Bar Diagram 2 is covered by CS properly. The width of Bar Diagram 2 is equal to the width of CS. The length of CS remains equal to the length of this bar diagram.

Side A covers the Bar Diagram 1 properly. The length of Side A remains equal to the length of Bar Diagram 1. The width of this bar diagram remains equal to the width of Side A.

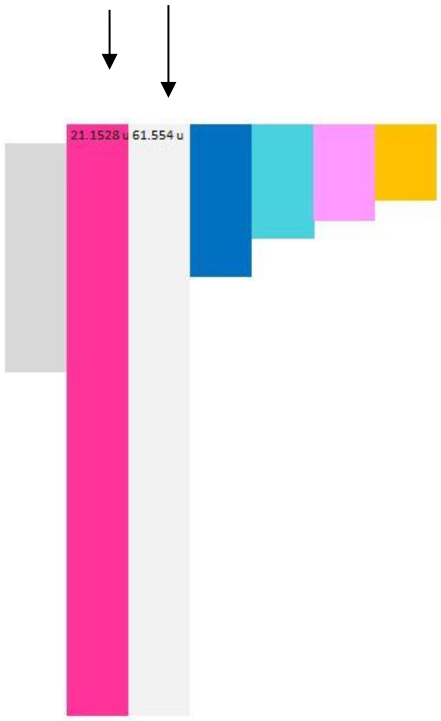



**Figure 57**

**33.** Now the SCALE looks like the following picture;

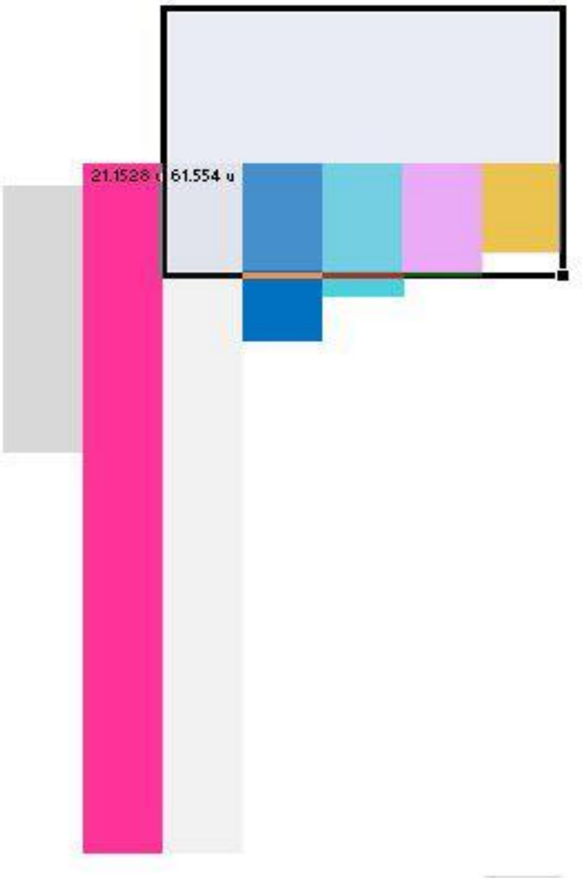



**Figure 58**

34. **The Measured or Predicted Values**

**With the help of SCALE, we find the values that remain close to the actual values. The numerical values (produced by this instrument) remain very close to the actual values (the maximum difference remains around 4%). For example, see these results:**

The experimental and evaluated data of authentic sources (e.g., NNDC, Brookhaven National Laboratory; Radiochemistry Society; LBNL; 'The NUBASE evaluation of nuclear and decay properties', etc.) are used to verify the results produced by SCALE.

**1) Zone of Stable/ Long-lived nuclides of the elements:-**

**The value of mass depicted by Bar Diagram 2 near the lower side of adjusted Slider-**

**Symbol of element, Value of mass (u);**

Mn, 54.96 u ; Ti, 48.36 u ; Co, 59.35 u ; Cu, 63.75 u ; Zn, 65.95 u ; Sr, 89.1 u; Zr, 93.79 u; Ru, 103.17 u ; Cd, 112.55 u ; In, 114.90 u ; Ag, 110.21 u; Pd, 107.86 u ; Ba, 136.79 u ; Eu, 153.89 u ; Gd, 156.33 u ; Tb, 158.77 u ; Ho, 163.66 u ; Er, 166.1 u ; Lu, 173.43 u ; Yb, 170.98 u ; Re, 183.21 u ; Ac, 223.60 u ; Pa, 228.63 u ; Np, 233.65 u ; Db, 263.80 u ; Cn, 281.39 u ; Fl, 286.41 u ; Uup, 288.93 u ; Lv; 291.44 u ; Uuo, 296.46 u ; Rb,86.76 u ; V, 50.56 u; Sc, 46.16 u; Tc, 100.83 u; etc.

**2) Beta minus decay:-**

Take the example of terbium (Tb). In the case of Tb, the Bar Diagram 2 (covered by CS) depicts a value of mass near the adjusted Slider. It is 158.77 u. See the Figure 51. The location above the lower side of Slider depicts the beta minus decay trend. For illustration, see these actual values of A[5];

160; 161; 162; 163; 164; 165; 166; 167; 168; 169; 170; 171; etc.

**Beta plus decay ------**

The location below the lower side of Slider depicts the beta plus decay trend. For illustration, see these actual values of A;

153; 152; 151; 150; 149; 148; 147; 146; etc.

**3) In the case of heavier synthetic elements, we determine which Compound Nucleus (CN) is involved in the Hot Fusion reaction, or which Compound Nucleus (CN) is involved in the Cold Fusion reaction:-**

**a)** In the case of **Rf**, the Bar Diagram 2 (covered by CS) depicts a value of mass near the adjusted Slider. It is 261.29 u. See the Figure 52. The location above the lower side of Slider depicts greater value of mass (i.e., greater than 261.29 u). Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 261.0 u.

For illustration, see these Compound Nuclei (involved in the Hot Fusion reaction) in the case of Rf ----

$^{264}$Rf ($^{242}$Pu + $^{22}$Ne); $^{264}$Rf ($^{248}$Cm + $^{16}$O); $^{263}$Rf ($^{249}$Bk + $^{14}$N); $^{266}$Rf ($^{244}$Pu + $^{22}$Ne); $^{264}$Rf ($^{238}$U + $^{26}$Mg); $^{262}$Rf ($^{249}$Cf + $^{13}$C).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 261.0 u.

For illustration;

$^{258}Rf$ ($^{208}Pb$ + $^{50}Ti$); $^{257}Rf$ ($^{207}Pb$ + $^{50}Ti$); $^{256}Rf$ ($^{206}Pb$ + $^{50}Ti$); $^{254}Rf$ ($^{204}Pb$ + $^{50}Ti$); $^{256}Rf$ ($^{48}Ti$ + $^{208}Pb$).

**b)** In the case of **Lr**, the identified value of mass is 258.77 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 258.0 u. For illustration;

$^{261}Lr$ ($^{243}Am$ + $^{18}O$); $^{259}Lr$ ($^{243}Am$ + $^{16}O$); $^{263}Lr$ ($^{248}Cm$ + $^{15}N$); $^{265}Lr$; $^{260}Lr$ ($^{246}Cm$ + $^{14}N$); $^{258}Lr$ ($^{244}Cm$ + $^{14}N$); $^{263}Lr$; $^{262}Lr$ ($^{252}Cf$ + $^{10}B$); $^{260}Lr$ ($^{249}Cf$ + $^{11}B$).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 258.0 u.

For illustration;

$^{255}Lr$ ($^{205}Tl$ + $^{50}Ti$); $^{257}Lr$ ($^{209}Bi$ + $^{48}Ca$); $^{253}Lr$ ($^{208}Pb$ + $^{45}Sc$); $^{255}Lr$; $^{253}Lr$ ($^{203}Tl$ + $^{50}Ti$).

**c)** In the case of **Uus**, the identified value of mass is 293.95 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 293.0 u. For illustration;

$^{297}Uus$ ($^{249}Bk$ + $^{48}Ca$).

**d)** In the case of **Hs**, the identified value of mass is 271.34 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 271.0 u. For illustration;

$^{274}Hs$ ($^{226}Ra$ + $^{48}Ca$) ; $^{271}Hs$ ($^{249}Cf$ + $^{22}Ne$) ; $^{274}Hs$ ($^{238}U$ + $^{36}S$) ; $^{272}Hs$ ($^{238}U$ + $^{34}S$) ; $^{274}Hs$ ($^{248}Cm$ + $^{26}Mg$).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 271.0 u.

For illustration;

$^{266}Hs$ ($^{58}Fe$ + $^{208}Pb$) ; $^{265}Hs$ ($^{58}Fe$ + $^{207}Pb$) ; $^{264}Hs$ ($^{206}Pb$ + $^{58}Fe$).

**e)** In the case of **Ds**, the identified value of mass is 276.36 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 276.0 u. For illustration;

$^{280}Ds$ ($^{232}Th$ + $^{48}Ca$) ; $^{278}Ds$ ($^{244}Pu$ + $^{34}S$).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 276.0 u.

For illustration; $^{272}Ds$ ($^{64}Ni$ + $^{208}Pb$) ; $^{270}Ds$ ($^{62}Ni$ + $^{208}Pb$).

**f)** In the case of **Bh**, the identified value of mass is 268.83 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 268.0 u.

For illustration;

$^{271}Bh$ ($^{22}Ne$ + $^{249}Bk$) ; $^{269}Bh$ ($^{238}U$ + $^{31}P$) ; $^{269}Bh$ ($^{26}Mg$ + $^{243}Am$).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 268.0 u.

For illustration; $^{263}Bh$ ($^{55}Mn$ + $^{208}Pb$) ; $^{263}Bh$ ($^{54}Cr$ + $^{209}Bi$) ; $^{261}Bh$ ($^{52}Cr$ + $^{209}Bi$).

**g)** In the case of **Mt**, the identified value of mass is 273.85 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 273.0 u. For illustration;

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 273.0 u.

For illustration; $^{267}Mt$ ($^{58}Fe$ + $^{209}Bi$) ; $^{267}Mt$ ($^{59}Co$ + $^{208}Pb$).

**h)** In the case of **Rg**, the identified value of mass is 278.88 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 278.0 u. For illustration;

$^{273}Rg$ ($^{65}Cu$ + $^{208}Pb$) ; $^{273}Rg$ ($^{64}Ni$ + $^{209}Bi$).

**i)** In the case of **Uut**, the identified value of mass is 283.90 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 283.0 u. For illustration;

$^{285}Uut$ ($^{237}Np$ + $^{48}Ca$).

**j)** In the case of **Uup**, the identified value of mass is 288.93 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 288.0 u. For illustration;

$^{289}Uup$ ($^{238}U$ + $^{51}V$) ; $^{291}Uup$ ($^{243}Am$ + $^{48}Ca$).

**k)** In the case of **Fl**, the identified value of mass is 286.41 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 286.0 u. For illustration;

$^{290}Fl$ ($^{48}Ca$ + $^{242}Pu$) ; $^{292}Fl$ ($^{48}Ca$ + $^{244}Pu$).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 286.0 u. For illustration; $^{284}Fl$ ($^{76}Ge$ + $^{208}Pb$).

**l)** In the case of **No**, the identified value of mass is 256.26 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 256.0 u. For illustration;

$^{258}$No ($^{232}$Th + $^{26}$Mg) ; $^{260}$No ($^{238}$U + $^{22}$Ne) ; $^{258}$No ($^{236}$U + $^{22}$Ne) ; $^{258}$No ($^{238}$U + $^{20}$Ne) ; $^{257}$No ($^{235}$U + $^{22}$Ne) ; $^{260}$No ($^{242}$Pu + $^{18}$O) ; $^{257}$No ($^{241}$Pu + $^{16}$O) ; $^{257}$No ($^{239}$Pu + $^{18}$O) ; $^{258}$No ($^{243}$Am + $^{15}$N) ; $^{257}$No ($^{243}$Am + $^{14}$N) ; $^{256}$No ($^{241}$Am + $^{15}$N) ; $^{262}$No ; $^{261}$No ($^{248}$Cm + $^{13}$C) ; $^{260}$No ($^{248}$Cm + $^{12}$C) ; $^{259}$No ($^{246}$Cm + $^{13}$C) ; $^{258}$No ($^{246}$Cm + $^{12}$C) ; $^{257}$No ($^{244}$Cm + $^{13}$C) ; $^{256}$No ($^{244}$Cm + $^{12}$C) ; $^{260}$No ; $^{262}$No ; $^{261}$No.

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 256.0 u. For illustration;

$^{256}$No ($^{208}$Pb + $^{48}$Ca) ; $^{252}$No ($^{208}$Pb + $^{44}$Ca) ; $^{255}$No ($^{207}$Pb + $^{48}$Ca ); $^{254}$No ($^{206}$Pb + $^{48}$Ca) ; $^{252}$No ($^{204}$Pb + $^{48}$Ca).

**m)** In the case of **Cn**, the identified value of mass is 281.39 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 281.0 u. For illustration;

$^{286}$Cn ($^{238}$U + $^{48}$Ca) ; $^{281}$Cn ($^{233}$U + $^{48}$Ca).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 281.0 u. For illustration; $^{276}$Cn ($^{208}$Pb + $^{68}$Zn) ; $^{272}$Cn ($^{184}$W + $^{88}$Sr) ; $^{278}$Cn ($^{208}$Pb + $^{70}$Zn).

**n)** In the case of **Sg**, the identified value of mass is 266.31 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 266.0 u. For illustration;

$^{267}$Sg ($^{18}$O + $^{249}$Cf) ; $^{268}$Sg ($^{30}$Si + $^{238}$U ) ; $^{270}$Sg ($^{22}$Ne + $^{248}$Cm).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 266.0 u. For illustration;

$^{262}$Sg ($^{54}$Cr + $^{208}$Pb) ; $^{261}$Sg ($^{54}$Cr + $^{207}$Pb) ; $^{260}$Sg ($^{51}$V + $^{209}$Bi) ; $^{260}$Sg ($^{52}$Cr + $^{208}$Pb).

**o)** In the case of **Lv**, the identified value of mass is 291.44 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 291.0 u. For illustration;

$^{292}$Lv ($^{238}$U + $^{54}$Cr) ; $^{296}$Lv ($^{248}$Cm + $^{48}$Ca) ; $^{293}$Lv ($^{245}$Cm + $^{48}$Ca).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 291.0 u. For illustration; $^{290}$Lv ($^{208}$Pb + $^{82}$Se).

**p)** In the case of **Db**, the identified value of mass is 263.80 u. Generally, the mass of CN (CN involved in the Hot Fusion reaction) remains greater than, or equal to 263.0 u. For illustration;

$^{263}$Db ($^{232}$Th + $^{31}$P) ; $^{265}$Db ($^{238}$U + $^{27}$Al) ; $^{263}$Db ($^{236}$U + $^{27}$Al) ; $^{265}$Db ($^{243}$Am + $^{22}$Ne) ; $^{263}$Db ($^{241}$Am + $^{22}$Ne) ; $^{267}$Db ($^{248}$Cm + $^{19}$F) ; $^{267}$Db ($^{249}$Bk + $^{18}$O) ; $^{265}$Db ($^{249}$Bk + $^{16}$O) ; $^{265}$Db ($^{250}$Cf + $^{15}$N) ; $^{264}$Db ($^{249}$Cf + $^{15}$N) ; $^{267}$Db ($^{254}$Es + $^{13}$C).

Generally, the mass of CN (CN involved in the Cold Fusion reaction) remains less than, or equal to 263.0 u. For illustration;

$^{259}$Db ($^{209}$Bi + $^{50}$Ti) ; $^{258}$Db ($^{209}$Bi + $^{49}$Ti) ; $^{257}$Db ($^{209}$Bi + $^{48}$Ti) ; $^{259}$Db ($^{208}$Pb + $^{51}$V) ; $^{258}$Db ($^{207}$Pb + $^{51}$V) ; $^{259}$Db ($^{205}$Tl + $^{54}$Cr).

**4) Two-neutron Separation Energy indicates the location of Isotope:-**

**We identify the locations of isotopes on the basis of values of two-neutron separation energy. For example, see the locations of isotopes identified in the case of Tb and Cr -----**

When two-neutron separation energy is about **22.66 MeV** (or 0.02433 u), the location that shows the value of mass **45.0 u** on CS. Here, the covered Bar Diagram 2 depicts 139.29 u in the case of Tb, and 51.43 u in the case of Cr. Now compare these with the actual values;

In the case of Tb, actual values of $A^5$ are 140, 141, 142, 143. In the case of Cr, actual values of $A^5$ are 51, 52.

When the value remains about **21.33 MeV** (or 0.02290 u), the location that shows value of mass **46.0 u** on CS. In the case of Tb, Bar Diagram 2 depicts 142.38 u. The actual values of A are 144, 145, 146.

When the value remains about **20.0 MeV** (or 0.02147 u), the location that shows value of mass **47.0 u** on CS. In the case of Tb, actual values of A are 147, 148. In the case of Cr, actual value of A is 53.

When the value remains about **18.66 MeV** (or 0.02003 u), the location that shows value of mass **48.0 u** on CS. In the case of Tb, Bar Diagram 2 depicts 148.57 u. The actual value of A is 148.

When the value of two-neutron separation energy is about **17.33 MeV** (or 0.01860 u), the location that shows value of mass **49.0 u** on CS. In the case of Tb, actual values of A are 149, 150. In the case of Cr, actual value of A is 54.

When the value remains about **16.0 MeV** (or 0.01718 u), the location that shows value of mass **50.0 u** on CS. In the case of Tb, actual values of A are 150, 151, 152, 153, 154, 155, 156, 157, 158. In the case of Cr, actual value of A is 55.

When the value of two-neutron separation energy is about **14.66 MeV** (or 0.01574 u), the location that shows value of mass **51.0 u** on CS. In the case of Tb, actual values of A are 159, 160, 161, 162. In the case of Cr, actual value of A is 56.

When the value of two-neutron separation energy is about **13.33 MeV** (or 0.01431 u), the location that shows value of mass **52.0 u** on CS. In the case of Tb, actual values of A are 161,162, 163. In the case of Cr, actual values of A are 57, 58.

When the value of two-neutron separation energy is about **12.0 MeV** (or 0.01288 u), the location that shows value of mass **53.0 u** on CS. In the case of Tb, actual values of A are 164, 165, 166, 167. In the case of Cr, actual value of A is 59.

When the value of two-neutron separation energy is about **10.66 MeV** (or 0.01144 u), the location that shows value of mass **54.0** u on CS. In the case of Tb, actual values of A are 168, 169. In the case of Cr, actual values of A are 60, 61, 62.

When the value of two-neutron separation energy is about **9.33 MeV** (or 0.01001 u), the location that shows value of mass **55.0 u** on CS. In the case of Tb, actual values of A are 170, 171. In the case of Cr, actual values of A are 62, 63, 64, 65.

When the value of two-neutron separation energy is about **8 MeV** (or 0.00859 u), the location that shows value of mass **56.0 u** on CS. In the case of Cr, actual values of A are 65, 66.

When the value remains about **6.66 MeV** (or 0.00715 u), the location that shows value of mass **57.0 u** on CS. In the case of Cr, Bar Diagram 2 depicts 65.14 u. The actual value of A is 67.

**5) r-process path, or r-process point:-**

The location (on CS) that shows the value of mass 58.0 u depicts the r-process path, or the r-process point. But in the case of elements found near the Magic Number, the location (on CS) that shows the value of mass 55.0 u depicts the r-process path, or the r-process point.

**Approximate r-process path, or r-process point** ----

The value of mass depicted by the location identified on Bar Diagram 2 (covered by CS) -----

**Symbol of element, Approximate value of mass (u);**

Fe, 72.0 u ; Co, 75.0 u ; Ge, 84.0 u ; As, 86.0 u ; Se, 89.0 u ; Br, 92.0 u ; Cu, 80.0 u ; Rb, 97.0 u ; Sr, 105.0 u ; Y, 108.0 u ; Zr, 110.0 u ; Nb, 113.0 u ; Mo, 116.0 u ; Tc, 119.0 u ; Ru, 122.0 u ; Rh, 124.0 u ; Ag , 130.0 u ; Cd, 133.0 u ; In, 135.0 u ; Sb , 134.0 u ; Te, 136.0 u ; Ce , 160.0 u ; Nd, 166.0 u ; Pm, 168.0 u ; Sm, 171.0 u ; Eu,174.0 u ; Gd, 177.0 u ; Tb, 180.0 u ; Yb, 193.0 u ; Lu, 196.0 u ; Ta, 202.0 u ; Hf, 199.0 u; etc.

**6) Location near One-neutron Dripline ($S_1n = 0$) of the element:-**

**The apex of Bar Diagram 2 (covered by CS) which depicts the maximum value of mass -**

**Symbol of element, Value of mass (u);**

Cr, 70.35 u ; Fe, 76.21 u ; Ni, 82.07 u ; Rb, 108.45 u ; Hg, 234.5 u ; Co, 79.14 u ; Sr, 111.38 u ; Rh, 131.9 u ; Pd, 134.83 u ; Nd, 175.87 u ; Nb, 120.18 u ; Cs, 161.21 u ; Fm, 293.1 u ; Zr, 117.25 u ; Th, 263.8 u ; In, 143.63 u; etc.

## Conclusion

The outcome of this empirical research explores the periodic trend in the nuclear properties. It helps us develop an instrument (SCALE) and make the visual comparison among the chemical elements, quickly. The developed instrument (SCALE) helps us measure the nuclear properties of elements. This instrument can be used to read the pattern of nuclear stability.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