Nuclear and Electronic Structure of Atoms

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Abstract. The plot of Extra Neutron number against the Z number of natural elements reveals a trend that shows the same periodicity observed in the chemical properties of elements. Nuclei appears to direct the electronic structure of atoms.

Different models of the nuclear structure have been proposed. When the electronic structure of atoms was elaborated, the nucleus only provided, with protons, a central positive charge to attract negative electrons [1].

The presence of a precise number of neutrons confers nuclear stability to selected isotopes of natural elements. The aim of the present work is to investigate whether a relationship exists between the number of Extra Neutrons (EN=A-2Z) in the nuclei of stable elements and the electronic structure of atoms.

Fig. 1 shows the number of EN in the nuclei of natural elements, plotted against the Z number. The weighted mean of EN for each element, calculated from [2], is reported. The electronic structure of atoms, the principal and azymutal (letters) quantum numbers, and the atomic volumes [3] are also shown.

The addition of EN to nuclei with the increase of atomic Z number takes place with upsurges and pauses.

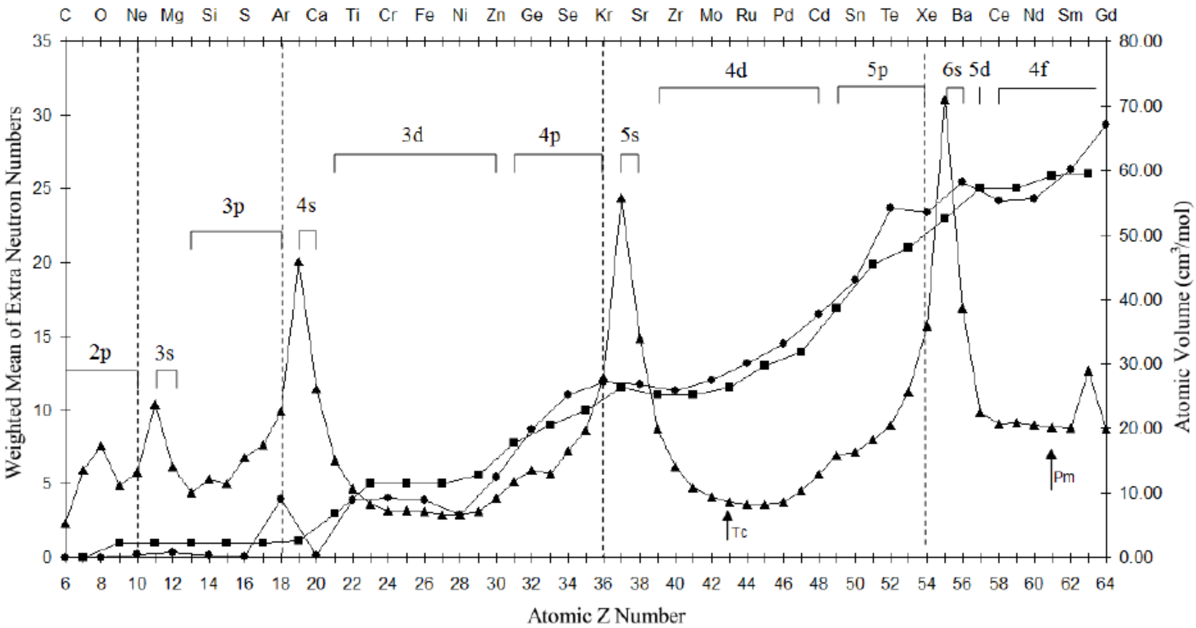


Fig. 1 - The figure shows, as a function of atomic Z number: 1) the weighted means of Extra Neutron (A-2Z) number for the isotopes of natural elements with even —◆— and odd —■— values of Z; 2) The electronic structure of atoms, principal and azymutal (letters) quantum numbers; 3) the atomic volume of atoms —▲—.

Going from $_5$B to approximately $_{64}$Gd, a sizable central share of the periodic table of elements, it is possible to single out four repetitive events (see also Fig.2) corresponding to the four sequences of electron additions: 2p →3s; 3p →4s; 3d→4p→5s; 4d→5p→6s. The sharp upsurges of EN addition to nuclei culminate at the completion of the six p electrons addition, leading to the electronic structure of the noble gases Ne, Ar, Kr and Xe. Following the noble gases, pauses of EN addition to nuclei, or even reductions in the number of EN, characterize alkaline metals and alkaline earths structures. Pauses extend somehow to 3d and 4d blocks. Hence, the trend of EN addition to nuclei of natural elements parallels the periodicity of the chemical and physical properties of elements, exemplified in Fig.1 by the values of the atomic volume. That is, EN addition to nuclei, a determinant of the stability of nuclear architecture, appears also as a determinant of the electronic structure of atoms.

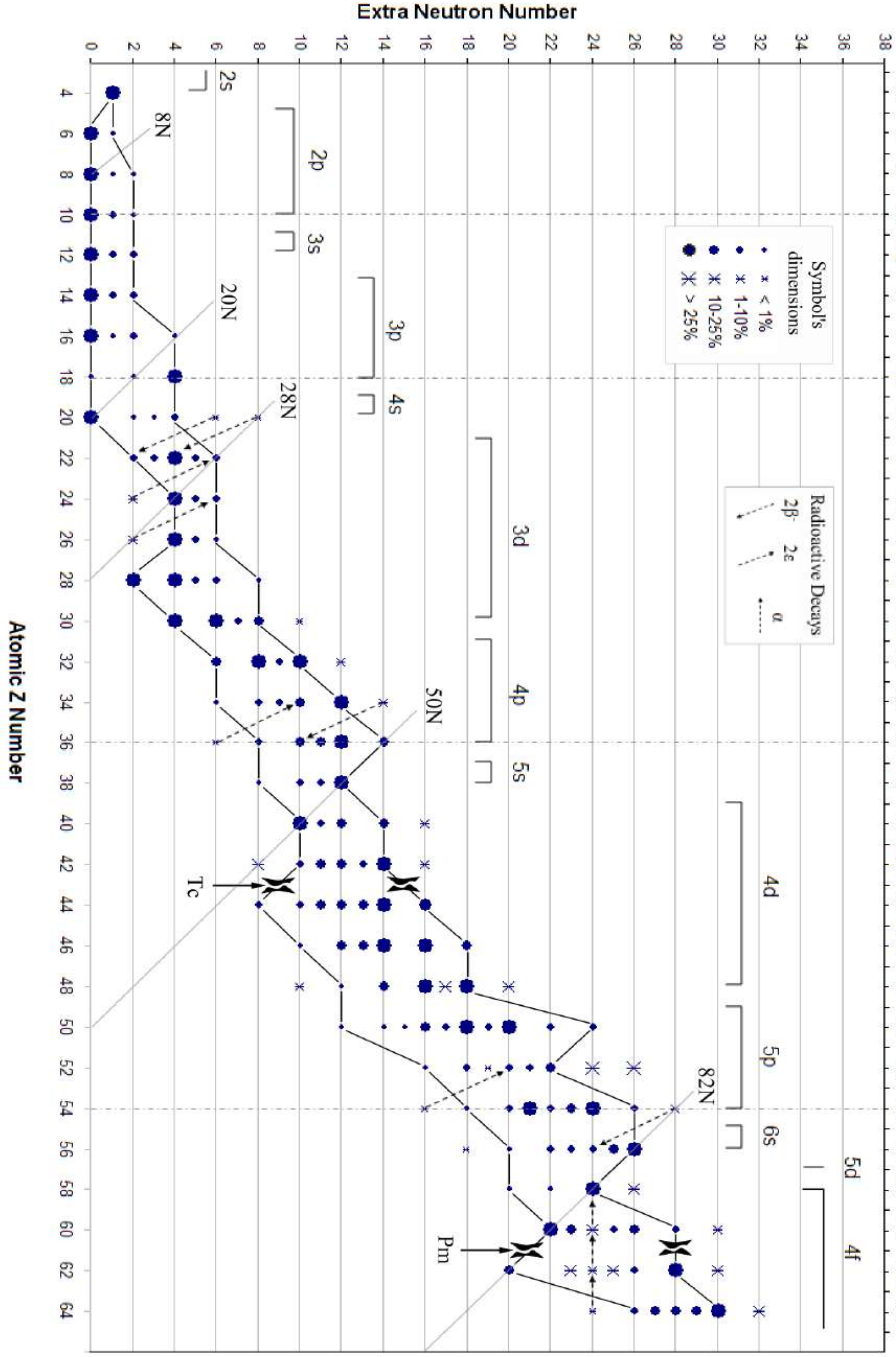
Moreover, the unstable elements Tc and Pm are both located seven places after the noble gases Kr and Xe. This can be read as a further link between the nuclear architecture and the electronic structure of atoms.

Fig. 2 shows the number of EN for the natural isotopes of each element [2] against Z number. Only the Z even elements are considered, a restriction not invalidating the substance of the present work. Lower and upper boundaries of the zone of stability of the isotopes of single elements are shown. Radioactive isotopes, even if extremely long lived, are distinguished from the stable isotopes and, for a few of them, the pathway of decay is shown. All decays lead to elements with stable isotopes inside the area of stability delimitated by the two boundaries (Fig. 2). This may suggest that the existing natural radioactive isotopes have been frozen in such a state at the time and in the conditions of their nucleosynthesis, blocking an otherwise faster transformation to stable elements.

The trend of the lower and, in particular, that of the upper boundary of stability in Fig. 2, agrees with the trend of EN addition to nuclei presented in Fig. 1 and with the electronic structure of atoms. However, differences exist between the two boundaries suggesting that the lowest and the highest EN numbers, required for nuclear stability of the isotopes of single elements, may have different physical meanings. Inside the zone of stability all even mass atoms are stable, but several odd mass atoms are unstable (Fig. 2).

Table 1

Extra Neutron Number of Solar System Isotopes of different elements (Fig.2)	Total Trapped Nucleons in Solar System Isotopes of different elements (Fig.2)
0	9.780.897.635
1	5.253.208
2	13.943.984
3	12.118
4	48.644.906
5	1.115.578
6	290.119
7	3.367
8	52.588
9	1.069
10	6.308
11	849
12	7.953
13	91
14	1.665
15	24
16	240
17	55
18	193
19	44



Extra Neutron Number
Atomic Z Number
Symbol's dimensions
< 1%
1-10%
10-25%
> 25%
Radioactive Decays
2β-
2ε
α
Be C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge Se Kr Sr Zr Mo Ru Pd Cd Sn Te Xe Ba Ce Nd Sm Gd
2s
2p
3s
3p
4s
3d
4p
5s
4d
5p
6s
5d
4f
8N
20N
28N
50N
82N
Tc
Pm

The shell model of nuclear structure stems from the existence of magic numbers of nucleons (Fig. 2) that confer enhanced stability to particular nuclei. Moreover atoms with magic numbers of protons and or neutrons show enhanced natural abundance (n.a.).This is not always true. For example 28, a magic number of neutrons, shows its effect on ^{52}Cr (83.8 % n.a.) but fails to show a clear effect on ^{50}Ti (5.3% n.a.) and on ^{54}Fe (5.8% n.a.). Instead the isotopes of the above elements with the highest abundance are ^{48}Ti (73.72 n.a.) and ^{56}Fe (91.75 % n.a.) in spite of no magic neutron number in their nuclei. The mass of an isotope in Fig. 2 is obtained by the addition of its EN number to twice the value of its atomic number.

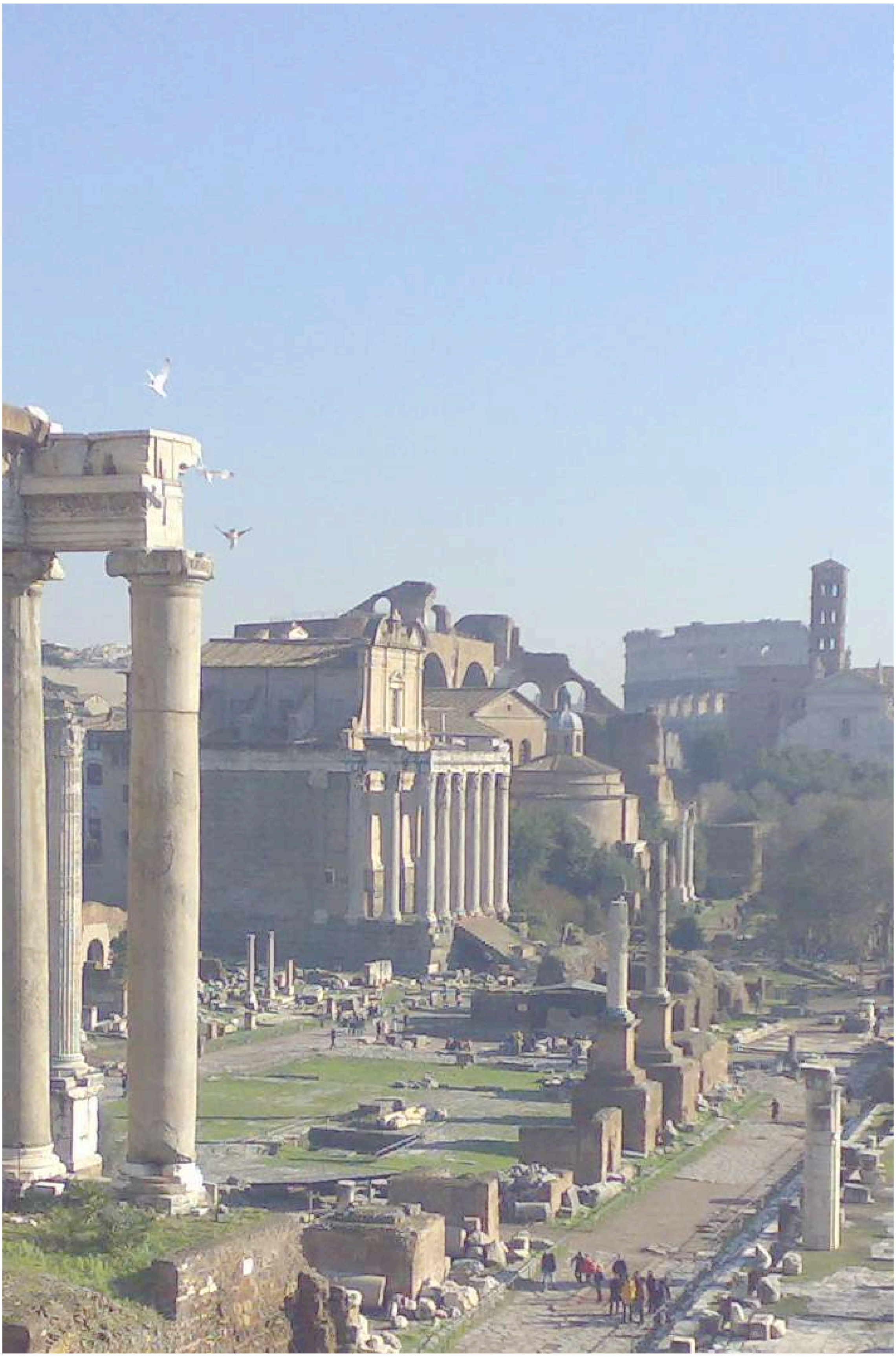
Inspection of Fig. 2 reveals that high natural abundance isotopes of different elements populate, in particular, the arrays with 0 and 4 EN.

This observation prompted the investigation of the Total Trapped Nucleons (TTN) in the nuclear species present in the arrays corresponding to single values of the EN number of Fig.2. Table 1 shows that 4 EN, and multiples of 4 EN in the nucleus, lead to enhanced Solar System Abundance (SSA) of the corresponding element's isotopes. Hence multiples of 4 EN appear to be a kind of magic numbers, at least up to 19 EN. This finding is particularly interesting in the case of ^{56}Fe, whose outstanding SSA does not find an explanation in the frame of classical magic numbers. TTN in a singular species was calculated as follows: TTN = SSA of an element, times the isotopic abundance of that species, times its atomic mass. SSA of elements, normalized to 10^6 atoms of Si, was obtained from [4].

One further consideration. Among the different periodic tables of elements [5], the one suggested in 1929 by the French biologist Janet [6], with an eight-period instead of the classical seven-period format, is in best accordance with the periodicity of EN addition to nuclei (Fig. 1 and Fig. 2).

References

[1] G. Herzberg, *Atomic Spectra and Atomic Structure*. (Dover Publications, New York, 1994)
[2] K. Tuli: *Nuclear Wallet Cards.* Sixt Ed. (2000)
[3] C.N. Singman: *J.Chem Ed.* **61** 137 (1984)
[4] K. Lodders: *The Astrophysical Journal*. **591** 1220 (2003)
[5] E.R. Scerri: *The Periodic Table.* (Oxford Univ. Press, 2007)
[6] G. Katz: *The Chemical Educator.* **6** 324 (2001)



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