Unified Field Theory and Topology of Nuclei

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Abstract This paper proposes that a nucleus has a lattice configuration. A nucleus can not be seen visually. The configuration of a nucleus is studied in theoretical models, such as lattice, NCFC, and water drop. There are a few theories study many body interactions in a nucleus, such as Ab initio calculation, BCS formalism, and SEMF. However, the precise structure of an isotope is not known. According to Unified Field Theory (UFT), a proton has the shape of an octahedron. Since the strong forces are along the axes of the octahedron of protons and neutron, the structure of ground state isotopes of any given element can be logically induced. Furthermore, only two of three axes of the octahedron nucleus possess interactive forces. Therefore, any nuclear structure has one layer only. Our results demonstrate that there is a configuration for any isotope. Mass, stability and configuration of an isotope are related. We anticipate our essay to be a starting point of new method that provides precise configuration for each isotope, theoretical mass calculation for an unknown isotope, and nuclear characteristics/stability analysis for a given configuration. For example, the best symmetrical lattice of an isotope can be selected from all possible lattices. The selected lattice for the isotope can decide the stability of the isotope.

Keywords: *Nuclear Physics, Particle Physics, Unified Field Theory*

1. Introduction

The latest UFT (e.g. [1], [2]-[5]) predicted that proton and neutron are in an octahedron shape (e.g. [5]) with three axes. The nuclear theories, such as Lattice model (e.g. [7],[8]-[31]), Water Drop model (e.g. [32],[33]-[36]), BCS formalism, Ab initio calculation, SEMF, can only speculate or model nuclear structure. As result, the existing theories can not predict the stabilities of Technetium (e.g. [37], [38]-[53]).

Neutron and proton are interacted mainly via two strong interactive axes.

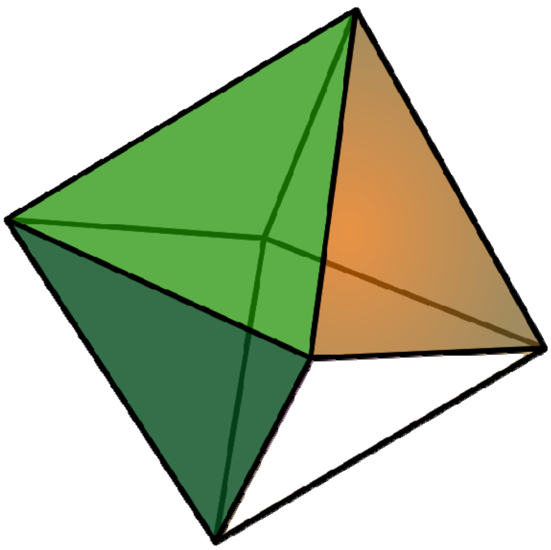

Fig. 1. Octahedron Proton

Octahedron protons and neutrons pile themselves up to make a nucleus. The configuration of proton/neutron octahedron pile decides the characteristics of a nucleus.

This paper analyzes the piling structures for some stable nuclei and unstable nuclei. The stability of a nucleus is largely based on whether the piling is symmetrical or not. A symmetrical nucleus is stable; otherwise, it is not stable.

2. Topology of Nuclei

The following UFT concepts will be used extensively in the paper:

The main structure of the Proton and Neutron are their axes (e.g. [5]): A^2, A^2 and A (some time B).

The component “A” has the following mass formula:

A = (2*3*5)

In addition,

A^2 = (2*3*5)* (2*3*5)

Component “B” has the following mass formula:

B = 2*2*4 (for proton) or 2*2*2*2 (for neutron)

2.1. Nuclear Lattice

When the proton count is more than four, the protons and neutrons are piled on a 2D plane formed by two main octahedron axes A^2 and A^2. The particles are aligned along the octahedron axes so that the roaming waves are moving along the straight lines.

2.2. Particle Piling

A proton has a single charge. The charged forces are evenly distributed vertical to the eight faces of the proton (e.g. [5]).

The proton structure needs to be symmetrical to make the structure stable.

3. Bonding Forces

3.1. Deuterium

A deuterium (e.g. [54], [55]-[61]) nucleus has a proton and a neutron. It is a stable symmetrical nucleus.

Proton:

$2A^2$+A+2*3+137/900+8/(137*137)+ (5/2)/(137*137*2*3)

Neutron:

Proton+137/(900*2.5*2)+10/(137*137)+ 1/(137*137*6)

When a proton and a neutron form a nucleus, one of the axes A from proton bonds with an A axis from neutron introduce a new bonding force of 137/900. Wave 2*3 becomes 2*2 to resonant with two nodes.

The wave 2.5 of neutron becomes 2 to resonant with the other 2*2 waves. The dissonant weak interaction of 2.5 with 2*3 no longer exists since 2*3 wave changed to 2*2.

Wave 2*2 weakly interacts with A (2*3*5). 5 is not direct energy and it has factor of ½. The self-dissonance weak interaction wave of 2*3*5 is:

5/(137*137*2*2*3) = 0.000022

A transformed proton and neutron has lower energy in the ^{2}H nucleus.

Proton:

$2A^2$ + A + 2*2+ 137/900 + 8/(137*137) + 137/(900*3*2) + 5/(137*137*2*2*3) = 1834.15267

Neutron:

$2A^2$ + A + 2*2 + 2 +137/900 + 8/(137*137) + 5/(137*137*2*2*3) + 1/(137*137*6)= 1836.17805

Strong interaction on the bonding point:

1*137/900

Total: 3670.48294

It matches exactly to the known value: 3670.48294 of ^{2}H mass.

3.2. Tritium

A deuterium (e.g. [62], [63]-[69]) nucleus has a proton and two neutron.

Since there are two neutrons, two negative waves 3 are shared among them. Proton only contains three axes:

3*($2A^2$ + A) + 2*3 = 5496

Two energy 3 waves strongly interact with three nucleons:

2*3*137/900 = 0.9133333

The 2.5 wave in neutron is missing; the neutron bonding remains, as there are one more neutrons than protons. The energy is reduced to one quarter of neutron bonding:

137/(900*5*2*2) = 0.0076111

The weak interaction on eight faces of octahedron structure:

8/(137*137) = 0.000426

The weak interaction of two wave 3:

2/(137*137) = 0.000107

The total mass: 5496.9215

It matches the experimental data of ^{3}H mass: 5497.9215

3.3. Helium-3

A helium-3 (e.g. [70], [71]-[78]) nucleus has two protons and a neutron. It is a stable symmetrical nucleus.

Since there is single neutron, only has single wave 5:

2*($2A^2$ + A) + ($2A^2$ + A + 5) = 5495

A^2 aggregates with A during interaction (A^2 + A = 930) as charged protons dominate the nucleus. Three nucleons strongly interact via two bonding points. But each bonding point has half the energy since the nucleons can rotate.

2*137/(930*2) = 0.147312

Dissonance wave of 5:

5*137/930 = 0.736559

Additional interactions are between 930, 30 and 5:

137/(930*30*5) = 0.001

The total mass: 5495.8851 matches the experimental data.

3.4. Helium-4

A helium-4 (e.g. [70], [71]-[78]) nucleus has two protons and two neutrons. It is a stable symmetrical nucleus.

Since there are two neutrons, two positive waves 3 are shared among them. The charged axis A changes to B (2*2*4) to interact with the central waves of $2A^2$. Wave 2*3 facilitates passing wave's direction changes. Energy formula becomes:

4*($2A^2$ + B + 2*3) + 2*3 = 7294

Four nucleons strongly interact via four bonding points. But each bonding point has half energy since the nucleons can rotate. A^2 aggregates with B during interaction (A^2 + B = 916) as charged protons dominate the nucleus:

4*137/((900 + 2*2*4)*2)= 0.29912664

Weak interaction:

4/137*137 = 0.0002131173

The total mass: 7294.29933975 matches the experimental data: 7294.299

4. Light Nuclei

4.1. Hydrogen

A hydrogen (e.g. [79], [80]-[96]) nucleus with a single proton is the simplest stable symmetrical nucleus.

A deuterium nucleus has a proton and a neutron. It is a stable symmetrical nucleus.

A tritium nucleus has a proton and two neutrons. It is a symmetrical but unstable nucleus and can be decayed into a Helium atom through beta decay.

4.2. Beryllium

A Beryllium-9 (e.g. [697], [98]-[107]) nucleus has four protons and five neutrons. It is a stable symmetrical nucleus.

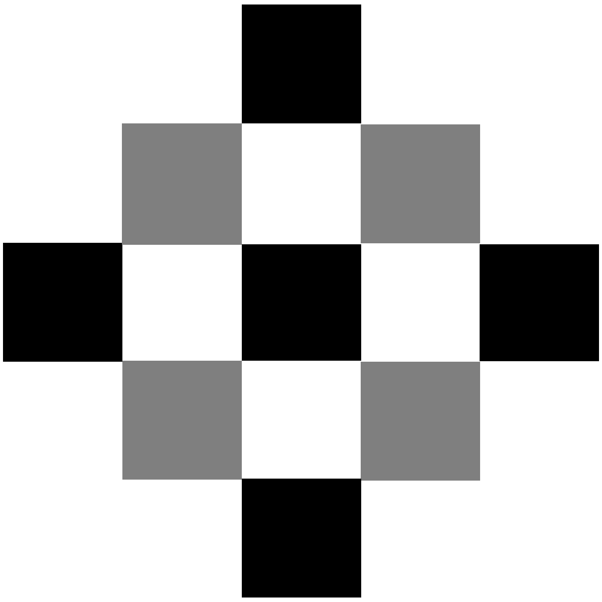

Fig. 2. ^{9}Beryllium

$9*(2A^2 + B + 2*2 + 2*2) + 2*2 + 2*2 = 16424$

Strong interaction:

9*137/(926*5) = 0.2663

Closely matches the experimental data: 16424.2504

4.3. Phosphorus

A Phosphorus-31 nucleus has fifteen protons and sixteen neutrons. It is a stable symmetrical nucleus.

Mass formula:

31*1816 + 20*(2+3)+11*(2*2)+2*3

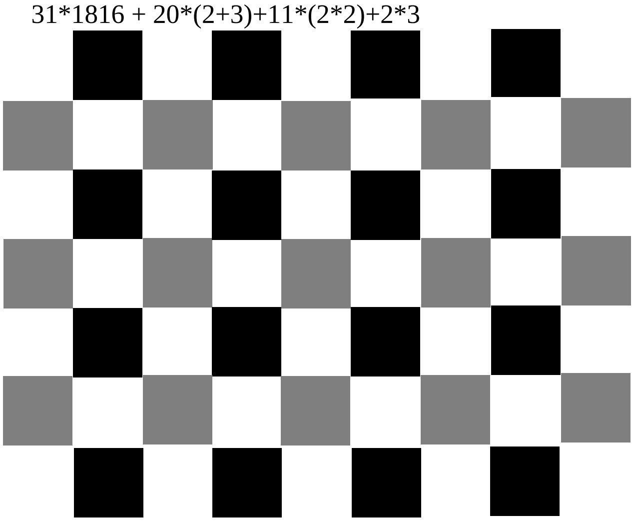

Fig. 3. ^{31}Phosphorus

5. Heavier Nuclei

5.1. Potassium

A Potassium-41 (e.g. [108], [109]-[113]) nucleus has nineteen protons and twenty two neutrons. It is a stable symmetrical nucleus.

Atomic number: 19

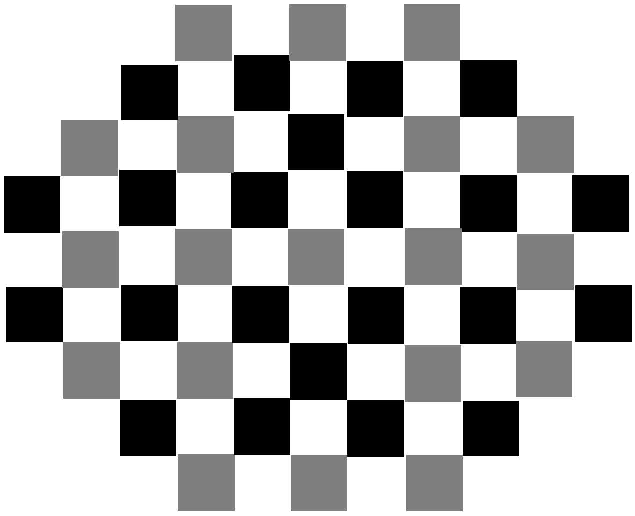

Fig. 4. Potassium structure

5.2. Ruthenium

A Ruthenium-104 (e.g. [114], [115],[116]) nucleus has 44 protons and 60 neutrons. It is a stable symmetrical (except the base square) nucleus.

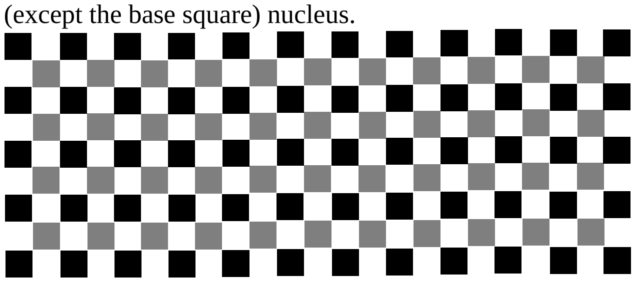

Fig. 5. Ruthenium Structure

5.3. Samarium

Atomic number: 62

The possible Structure for ^{144}Samarium:

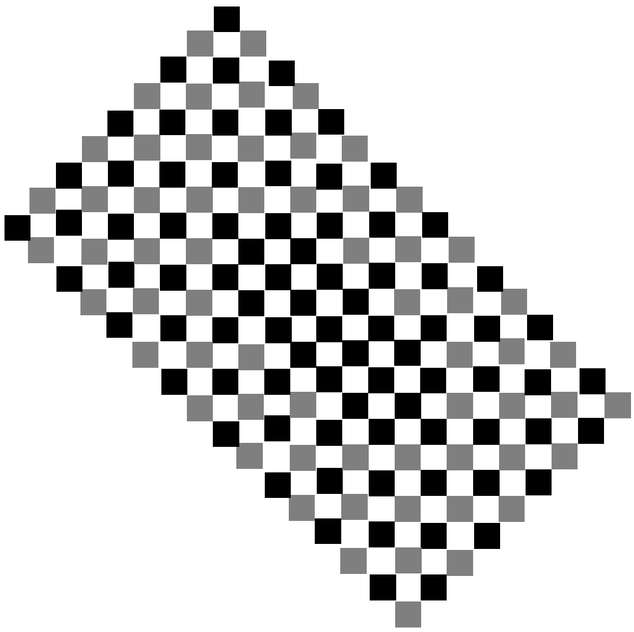

Fig. 6. ^{144}Samarium

The Structure for ^{150}Samarium:

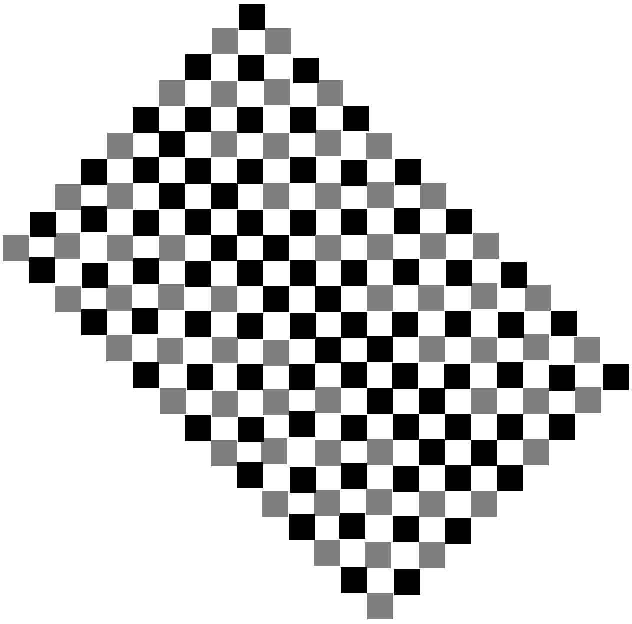

Fig. 7. ^{150}Samarium

The Structure for ^{152}Samarium: 8*19

The Structure for ^{154}Samarium: 14*11

5.4. Ytterbium

Atomic number: 70

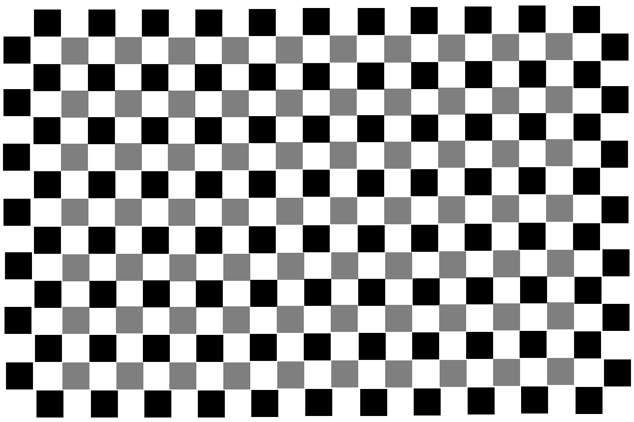

Fig. 8. ^{172}Yetterbium

5.5. Thulium

Atomic number: 69
The Structure for ^{169}Thulium:

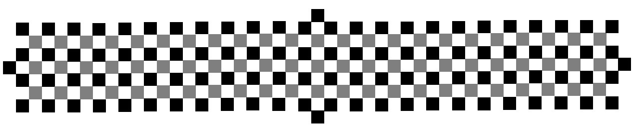

Fig. 9. ^{169}Thulium

5.6. Lead

Atomic number: 82
The Structure for ^{204}Lead:

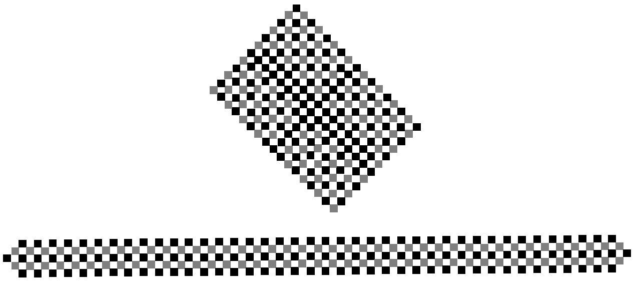

Fig. 10. ^{204}Lead

The Structure for ^{206}Lead:

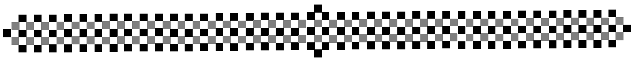

Fig. 11. ^{206}Lead

The Structure for ^{207}Lead:

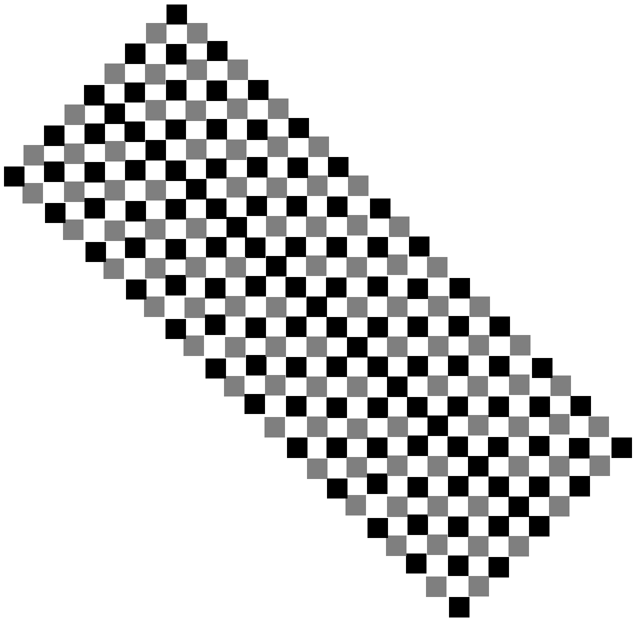

Fig. 12. ^{207}Lead

The Structure for ^{208}Lead:

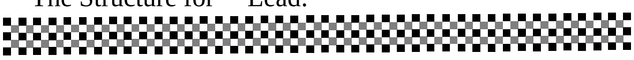

Fig. 13. ^{208}Lead

5.7. Uranium

Atomic number 92

The Structure for ^{238}Uranium (e.g. [117], [118],[118]):

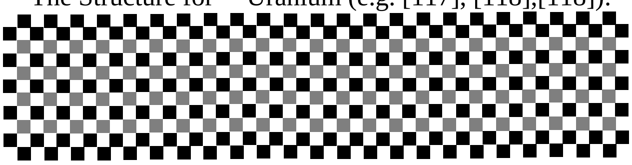

Fig. 14. ^{238}Urarium

The Structure for ^{236}Uranium:

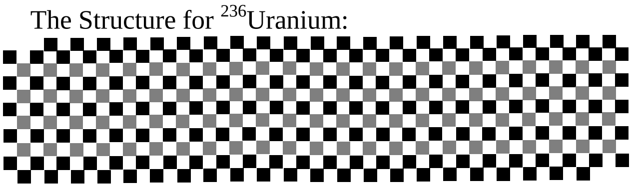

Fig. 15. ^{236}Urarium

The Structure for ^{235}Uranium:

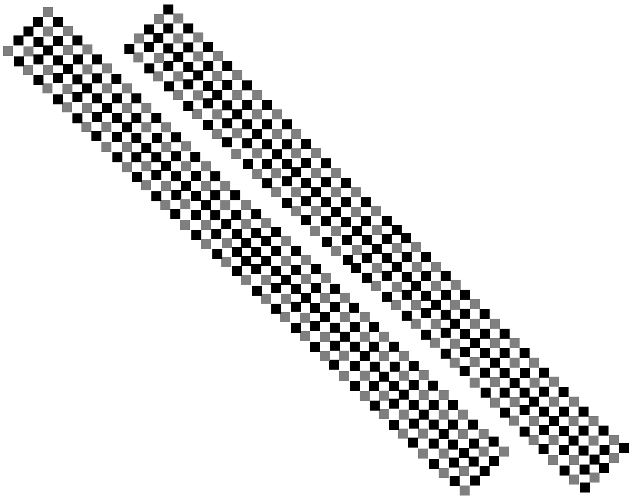

Fig. 16. ^{235}Urarium

The Structure for ^{234}Uranium:

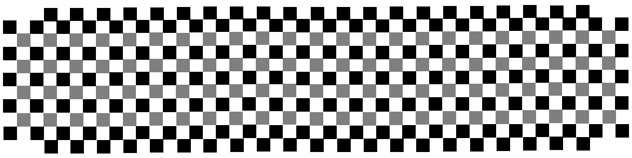

Fig. 17. ^{234}Urarium

The Structure for ^{233}Uranium:

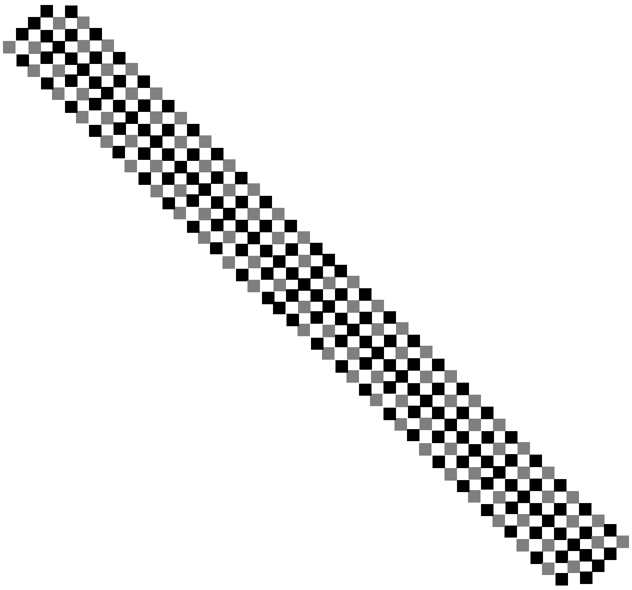

Fig. 18. ^{233}Urarium

6. Unstable Nuclei

6.1. Technetium

Atomic number 43

Technetium (e.g. [37], [38]-[53]) has no stable isotopes.
The Structure for ^{99}Technetium:

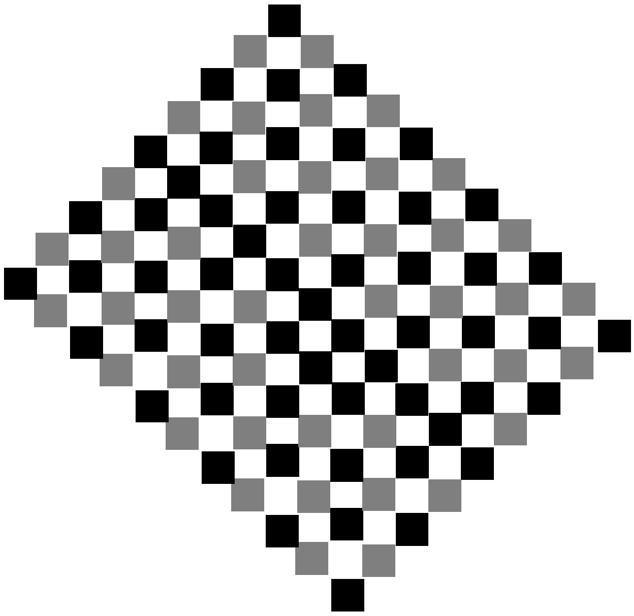

Fig. 19. ^{99}Technetium

The Structure for ^{98}Technetium:

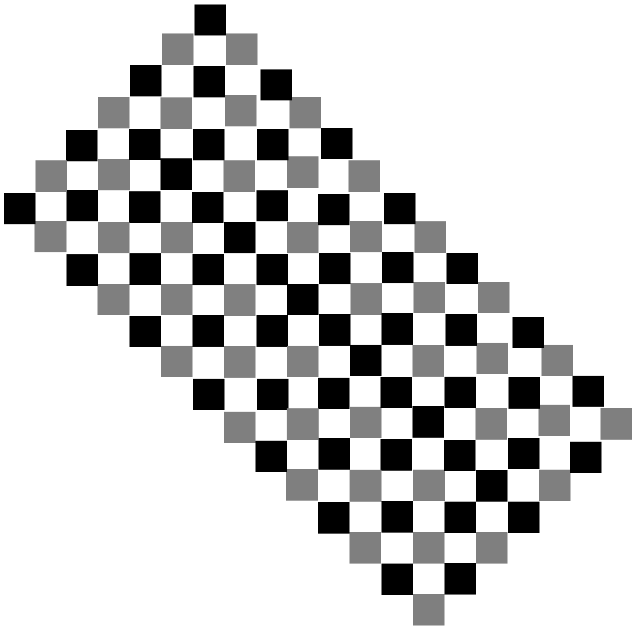

Fig. 20. ^{98}Technetium

The Structure for ^{97}Technetium:

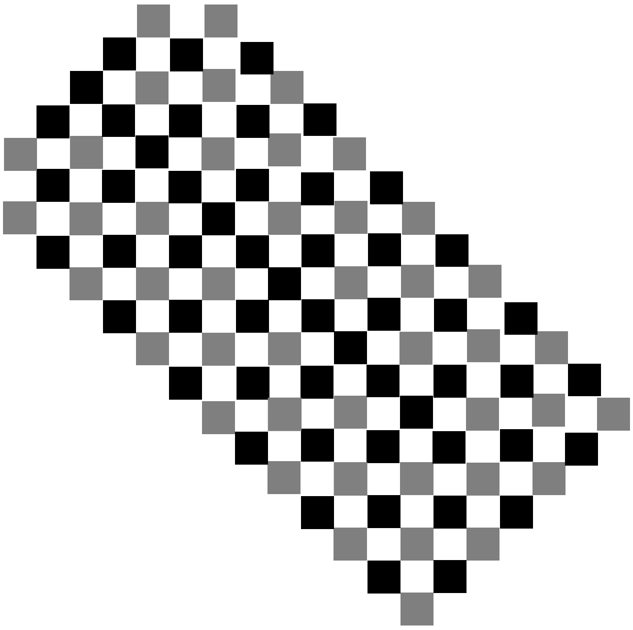

Fig. 21. ^{97}Technetium

6.2. Promethium

Atomic number 61

Promethium (e.g. [129], [130]-[133]) has no stable isotopes.

There are a few relatively stable isotopes:

The Structure for ^{145}Promethium:

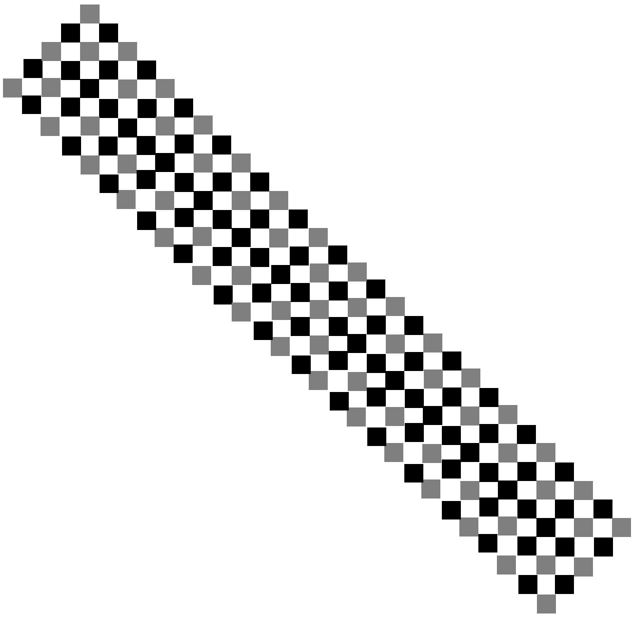

Fig. 22. ^{145}Promethium

7. Conclusions

1. The structures of nuclei are mainly the result of octahedron shaped protons and neutrons piling in a two dimensional plane.

2. Piled neutrons and protons keep the $2A^2$ structure. When atomic number is greater than two, 2*3*5 + 2*3 will be changed. Proton will have 2*2*4 + 2*2 or 2*2*4 + (2+3) structure. Neutron will have 2*2*2*2 + 2*2 or 2*2*2*2 + (2+3) structure.

3. Symmetrical piling is required for a stable nucleus.

References

[1] Cao, Zhiliang, and Henry Gu Cao. "SR Equations without Constant One-Way Speed of Light." International Journal of Physics 1.5 (2013): 106-109.

[2] Cao, Henry Gu, and Zhiliang Cao. "Drifting Clock and Lunar Cycle." International Journal of Physics 1.5 (2013): 121-127.

[3] Zhiliang Cao, Henry Gu Cao. Unified Field Theory. American Journal of Modern Physics. Vol. 2, No. 6, 2013, pp. 292-298. doi: 10.11648/j.ajmp.20130206.14.

[4] Cao, Zhiliang, and Henry Gu Cao. "Non-Scattering Photon Electron Interaction." Physics and Materials Chemistry 1, no. 2 (2013): 9-12.

[5] Cao, Zhiliang, and Henry Gu Cao. "Unified Field Theory and the Configuration of Particles." International Journal of Physics 1.6 (2013): 151-161.

[6] Cao, Zhiliang, and Henry Gu Cao. "Unified Field Theory and the Hierarchical Universe." International Journal of Physics 1.6 (2013): 162-170.

[7] S.R. Beane, P.F.Bedaque,K. Orginos, M.J. Savage, Phys. Rev. Lett. 97 (2006) 012001, hep-lat/0602010

[8] N. Ishii, S. Aoki and T. Hatsuda, Phys. Rev. Lett. 99, 022001 (2007).

[9] Noriyoshi Ishii, PoS LAT2009:019,2009.

[10] T. Yamazaki, Y. Kuramashi, A. Ukawa, Phys. Rev. D81:111504,2010. , arXiv:0912.1383 [hep-lat]

[11] H.M. Muller, S.E. Koonin , R. Seki, U. van Kolck, Phys. Rev. C61, 044320 (2000).

[12] D. Lee, B. Borasoy, Th Schaefer, Phys. Rev. C 70, 014007 (2004)

[13] E. Epelbaum, H. Krebs, D. Lee, U. Meissner, Eur. Phys. J. A45, 335-352, 2010.

[14] D. Lee, Prog. Part. Nucl. Phys. 63, 117 (2009), arXiv:0804.3501 [nucl-th].

[15] Yukawa, Proc. Math. Soc. Jap 17 (1935) 48

[16] V.G. Stoks et al, Phys. Rev. C49 (1994) 2950

[17] R.B. Wiringa et al, Phys. Rev. C51 (1995) 38

[18] R. Machleidt, Phys. Rev. C63 (2001) 0240041

[19] H. Kamada et al, Phys. Rev. C64 (2001) 044001, S. Pieper, Nucl. Phys. A751 (2005) 516

[20] S. Weinberg, Nucl. Phys. B363 (1991) 3

[21] C. Ordonez et al, Phys. Rev. C 53 (1996) 2086

[22] E. Epelbaum, W. Glockle, U.G. Meissner, Nucl. Phys. A671 (2000) 295. 14

[23] I. Montvay and G. Munster, Quantum Fields on a Lattice, Cambridge Univ. Press (1994)

[24] F. de Soto, J. Carbonell, C. Roiesnel, Ph. Boucaud, J.P. Leroy, O. Pene, Nucl. Phys. B Proc. Suppl. 164 (2007) 252.

[25] Y. Saad Iterative method for sparse linear systemManchester University Press (2000).

[26] F. de Soto, J. Carbonell, C. Roiesnel, Ph. Boucaud, J.P. Leroy, O. Pene, Eur. Phys. J A31, 777 (2007); hep-lat/0610084

[27] F. de Soto, J. Carbonell, C. Roiesnel, Ph. Boucaud, J.P. Leroy, O. Pene, Nucl. Phys. A 790 (2007) 410 ; hep-lat/0610086

[28] T. Nieuwenhuis, J.A. Tjon, Phys. Rev. Lett. 77 (1996) 814

[29] J. Polonyi, J. Shigemitsu, Phys.Rev. D38 (1988) 3231; I. Lee, J. Shigemitsu and R.E. Shrock, Nucl. Phys. B330 (1990) 225; I. Lee, J. Shigemitsu and R.E. Shrock, Nucl. Phys. B334 (1990) 265.

[30] P. Gerhold, K, Jansen, JHEP 0710:001,2007 , hep-lat 0707.3849

[31] P. Gerhold, K. Jansen, JHEP 1004:094,2010, [hep-lat] 1002.4336

[32] von Weizsäcker, C. F. (1935). "Zur Theorie der Kernmassen". Zeitschrift für Physik (in German) 96 (7–8): 431–458. Bibcode:1935ZPhy...96..431W. doi:10.1007/BF01337700.

[33] Bailey, D. "Semi-empirical Nuclear Mass Formula". PHY357: Strings & Binding Energy. University of Toronto. Retrieved 2011-03-31.

[34] Krane, K. (1988). Introductory Nuclear Physics. John Wiley & Sons. p. 68. ISBN 0-471-85914-1.

[35] Wapstra, A. H. (1958). "Atomic Masses of Nuclides". External Properties of Atomic Nuclei. Springer. pp. 1–37. doi:10.1007/978-3-642-45901-6_1. ISBN 978-3-642-45902-3.

[36] Rohlf, J. W. (1994). Modern Physics from a to Z0. John Wiley & Sons. ISBN 978-0471572701.

[37] "Technetium: technetium(I) fluoride compound data". OpenMOPAC.net. Retrieved 2007-12-10.

[38] Jonge, F. A. A.; Pauwels, EK (1996). "Technetium, the missing element". European Journal of Nuclear Medicine 23 (3): 336–44. doi:10.1007/BF00837634. PMID 8599967.

[39] Holden, N. E. "History of the Origin of the Chemical Elements and Their Discoverers". Brookhaven National Laboratory. Retrieved 2009-05-05.
[40] Yoshihara, H. K. (2004). "Discovery of a new element 'nipponium': re-evaluation of pioneering works of Masataka Ogawa and his son Eijiro Ogawa". Atomic spectroscopy (Spectrochim. Acta, Part B) 59 (8): 1305–1310. Bibcode:2004AcSpe..59.1305Y. doi:10.1016/j.sab.2003.12.027.
[41] van der Krogt, P. "Elentymolgy and Elements Multidict, "Technetium"". Retrieved 2009-05-05.
[42] Emsley 2001, p. 423
[43] Armstrong, J. T. (2003). "Technetium". Chemical & Engineering News. doi:10.1021/cen-v081n036.p110. Retrieved 2009-11-11.
[44] Nies, K. A. (2001). "Ida Tacke and the warfare behind the discovery of fission". Retrieved 2009-05-05.
[45] Weeks, M. E. (1933). "The discovery of the elements. XX. Recently discovered elements". Journal of Chemical Education 10 (3): 161–170. Bibcode:1933JChEd..10..161W. doi:10.1021/ed010p161.
[46] Zingales, R. (2005). "From Masurium to Trinacrium: The Troubled Story of Element 43". Journal of Chemical Education 82 (2): 221–227. Bibcode:2005JChEd..82..221Z. doi:10.1021/ed082p221.
[47] Heiserman 1992, p. 164
[48] Segrè, Emilio (1993). A Mind Always in Motion: the Autobiography of Emilio Segrè. Berkeley, California: University of California Press. pp. 115–118. ISBN 0520076273.
[49] Perrier, C.; Segrè, E. (1947). "Technetium: The Element of Atomic Number 43". Nature 159 (4027): 24. Bibcode:1947Natur.159...24P. doi:10.1038/159024a0. PMID 20279068.
[50] Emsley, J. (2001). Nature's Building Blocks: An A-Z Guide to the Elements. New York: Oxford University Press. pp. 422–425. ISBN 0-19-850340-7.
[51] "Chapter 1.2: Early Days at the Berkeley Radiation Laboratory". The transuranium people: The inside story. University of California, Berkeley & Lawrence Berkeley National Laboratory. 2000. p. 15. ISBN 1-86094-087-0.
[52] Merrill, P. W. (1952). "Technetium in the stars". Science 115 (2992): 479–89 [484]. Bibcode:1952Sci...115..479.. doi:10.1126/science.115.2992.479.
[53] Dan O'Leary "The deeds to deuterium" Nature Chemistry 4, 236 (2012). doi:10.1038/nchem.1273. "Science: Deuterium v. Diplogen". Time. 19 February 1934.
[54] Hartogh, Paul; Lis, Dariusz C.; Bockelée-Morvan, Dominique; De Val-Borro, Miguel; Biver, Nicolas; Küppers, Michael; Emprechtinger, Martin; Bergin, Edwin A. et al. (2011). "Ocean-like water in the Jupiter-family comet 103P/Hartley 2". Nature 478 (7368): 218–220. Bibcode:2011Natur.478..218H. doi:10.1038/nature10519. PMID 21976024.
[55] Hersant, Franck; Gautier, Daniel; Hure, Jean-Marc (2001). "A Two-dimensional Model for the Primordial Nebula Constrained by D/H Measurements in the Solar System: Implications for the Formation of Giant Planets". The Astrophysical Journal 554: 391. Bibcode:2001ApJ...554..391H. doi:10.1086/321355. "see fig. 7. for a review of D/H ratios in various astronomical objects"
[56] Nomenclature of Inorganic Chemistry. Chemical Nomenclature and Structure Representation Division, IUPAC. Retrieved 2007-10-03.
[57] Hébrard, G.; Péquignot, D.; Vidal-Madjar, A.; Walsh, J. R.; Ferlet, R. (7 Feb 2000), Detection of deuterium Balmer lines in the Orion Nebula
[58] Weiss, Achim. "Equilibrium and change: The physics behind Big Bang Nucleosynthesis". Einstein Online. Retrieved 2007-02-24.
[59] IUPAC Commission on Nomenclature of Inorganic Chemistry (2001). "Names for Muonium and Hydrogen Atoms and their Ions" (PDF). Pure and Applied Chemistry 73 (2): 377–380. doi:10.1351/pac200173020377.
[60] "Cosmic Detectives". The European Space Agency (ESA). 2 April 2013. Retrieved 2013-04-15.
[61] Lucas, L. L. and Unterweger, M. P. (2000). "Comprehensive Review and Critical Evaluation of the Half-Life of Tritium". Journal of Research of the National Institute of Standards and Technology 105 (4): 541. doi:10.6028/jres.105.043.
[62] Nuclide safety data sheet: Hydrogen-3. ehso.emory.edu
[63] Zerriffi, Hisham (January 1996). "Tritium: The environmental, health, budgetary, and strategic effects of the Department of Energy's decision to produce tritium". Institute for Energy and Environmental Research. Retrieved 2010-09-15.
[64] Jones, Greg (2008). "Tritium Issues in Commercial Pressurized Water Reactors". Fusion Science and Technology 54 (2): 329–332.
[65] ublette, Carey (2006-05-17). "Nuclear Weapons FAQ Section 12.0 Useful Tables". Nuclear Weapons Archive. Retrieved 2010-09-19.
[66] Whitlock, Jeremy. "Section D: Safety and Liability – How does Ontario Power Generation manage tritium production in its CANDU moderators?". Canadian Nuclear FAQ. Retrieved 2010-09-19.
[67] "Tritium (Hydrogen-3) – Human Health Fact sheet". Argonne National Laboratory. August 2005. Retrieved 2010-09-19.
[68] Serot, O.; Wagemans, C.; Heyse, J. (2005). "New Results on Helium and Tritium Gas Production From Ternary Fission". International conference on nuclear data for science and technology. AIP Conference Proceedings 769: 857–860. doi:10.1063/1.1945141.
[69] Fa WenZhe & Jin YaQiu (December 2010). "Global inventory of Helium-3 in lunar regoliths estimated by a multi-channel microwave radiometer on the Chang-E 1 lunar satellite".
[70] Slyuta, E. N.; Abdrakhimov, A. M.; Galimov, E. M. (March 12–16, 2007). "The Estimation of Helium-3 Probable Reserves in Lunar Regolith". 38th Lunar and Planetary Science Conference. p. 2175.
[71] Cocks, F. H. (2010). "3He in permanently shadowed lunar polar surfaces". Icarus 206 (2): 778–779. Bibcode:2010Icar..206..778C. doi:10.1016/j.icarus.2009.12.032.
[72] Oliphant, M. L. E.; Harteck, P.; Rutherford, E. (1934). "Transmutation Effects Observed with Heavy Hydrogen". Proceedings of the Royal Society A 144 (853): 692–703. Bibcode:1934RSPSA.144..692O. doi:10.1098/rspa.1934.0077. JSTOR 2935553.
[73] "Lawrence and His Laboratory: Episode: A Productive Error". Newsmagazine Publication. 1981. Retrieved 2009-09-01.
[74] Osheroff, D. D.; Richardson, R. C.; Lee, D. M. (1972). "Evidence for a New Phase of Solid He3". Physical Review Letters 28 (14): 885–888. Bibcode:1972PhRvL..28..885O. doi:10.1103/PhysRevLett.28.885.
[75] Osheroff, D. D.; Gully, W. J.; Richardson, R. C.; Lee, D. M. (1972). "New Magnetic Phenomena in Liquid He3 below 3 mK". Physical Review Letters 29 (14): 920–923. Bibcode:1972PhRvL..29..920O. doi:10.1103/PhysRevLett.29.920.
[76] Leggett, A. J. (1972). "Interpretation of Recent Results on He3 below 3 mK: A New Liquid Phase?". Physical Review Letters 29 (18): 1227–1230. Bibcode:1972PhRvL..29.1227L. doi:10.1103/PhysRevLett.29.1227.
[77] Leawoods, Jason C.; Yablonskiy, Dmitriy A.; Saam, Brian; Gierada, David S.; Conradi, Mark S. (2001). "Hyperpolarized 3He Gas Production and MR Imaging of the Lung". Concepts in Magnetic Resonance 13: 277–293.
[78] Simpson, J.A.; Weiner, E.S.C. (1989). "Hydrogen". Oxford English Dictionary 7 (2nd ed.). Clarendon Press. ISBN 0-19-861219-2.
[79] "Hydrogen". Van Nostrand's Encyclopedia of Chemistry. Wylie-Interscience. 2005. pp. 797–799. ISBN 0-471-61525-0.
[80] Emsley, John (2001). Nature's Building Blocks. Oxford: Oxford University Press. pp. 183–191. ISBN 0-19-850341-5.
[81] Stwertka, Albert (1996). A Guide to the Elements. Oxford University Press. pp. 16–21. ISBN 0-19-508083-1.
[82] Wiberg, Egon; Wiberg, Nils; Holleman, Arnold Frederick (2001). Inorganic chemistry. Academic Press. p. 240. ISBN 0123526515.
[83] "Magnetic susceptibility of the elements and inorganic compounds". CRC Handbook of Chemistry and Physics (81st ed.). CRC Press.
[84] Palmer, D. (13 September 1997). "Hydrogen in the Universe". NASA. Retrieved 2008-02-05.
[85] Presenter: Professor Jim Al-Khalili (2010-01-21). "Discovering the Elements". Chemistry: A Volatile History. 25:40 minutes in. BBC. BBC Four.
[86] "Hydrogen Basics — Production". Florida Solar Energy Center. 2007. Retrieved 2008-02-05.
[87] Rogers, H.C. (1999). "Hydrogen Embrittlement of Metals". Science 159 (3819): 1057–1064. Bibcode:1968Sci...159.1057R. doi:10.1126/science.159.3819.1057. PMID 17775040.
[88] Christensen, C.H.; Nørskov, J.K.; Johannessen, T. (9 July 2005). "Making society independent of fossil fuels — Danish researchers reveal new technology". Technical University of Denmark. Retrieved 2008-03-28. [dead link]
[89] "Dihydrogen". O=CHem Directory. University of Southern Maine. Retrieved 2009-04-06.
[90] Carcassi, M.N.; Fineschi, F. (2005). "Deflagrations of H2–air and CH4–air lean mixtures in a vented multi-compartment

environment". Energy 30 (8): 1439–1451. doi:10.1016/j.energy.2004.02.012.
[91] Committee on Alternatives and Strategies for Future Hydrogen Production and Use, US National Research Council, US National Academy of Engineering (2004). The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs. National Academies Press. p. 240. ISBN 0-309-09163-2.
[92] Patnaik, P (2007). A comprehensive guide to the hazardous properties of chemical substances. Wiley-Interscience. p. 402. ISBN 0-471-71458-5.
[93] Clayton, D.D. (2003). Handbook of Isotopes in the Cosmos: Hydrogen to Gallium. Cambridge University Press. ISBN 0-521-82381-1.
[94] Millar, Tom (December 10, 2003). "Lecture 7, Emission Lines — Examples". PH-3009 (P507/P706/M324) Interstellar Physics. University of Manchester. Retrieved 2008-02-05.
[95] Stern, David P. (2005-05-16). "The Atomic Nucleus and Bohr's Early Model of the Atom". NASA Goddard Space Flight Center (mirror). Retrieved 2007-12-20.
[96] "Beryllium: Beryllium(I) Hydride compound data". bernath.uwaterloo.ca. Retrieved 2007-12-10.
[97] Haynes, William M., ed. (2011). CRC Handbook of Chemistry and Physics (92nd ed.). CRC Press. p. 14.48. ISBN 1439855110.
[98] Jakubke, Hans-Dieter; Jeschkeit, Hans, eds. (1994). Concise Encyclopedia Chemistry. trans. rev. Eagleson, Mary. Berlin: Walter de Gruyter.
[99] Puchta, Ralph (2011). "A brighter beryllium". Nature Chemistry 3 (5): 416. Bibcode:2011NatCh...3..416P. doi:10.1038/nchem.1033. PMID 21505503.
[100] Behrens, V. (2003). "11 Beryllium". In Beiss, P. Landolt-Börnstein – Group VIII Advanced Materials and Technologies: Powder Metallurgy Data. Refractory, Hard and Intermetallic Materials 2A1. Berlin: Springer. pp. 1–11. doi:10.1007/10689123_36. ISBN 978-3-540-42942-5.
[101] Hausner, Henry H (1965). "Nuclear Properties". Beryllium its Metallurgy and Properties. University of California Press. p. 239.
[102] Ekspong, G. (1992). Physics: 1981–1990. World Scientific. pp. 172 ff. ISBN 978-981-02-0729-8.
[103] Emsley 2001, p. 56.
[104] "Beryllium: Isotopes and Hydrology". University of Arizona, Tucson. Retrieved 10 April 2011.
[105] Whitehead, N; Endo, S; Tanaka, K; Takatsuji, T; Hoshi, M; Fukutani, S; Ditchburn, Rg; Zondervan, A (Feb 2008). "A preliminary study on the use of (10)Be in forensic radioecology of nuclear explosion sites". Journal of environmental radioactivity 99 (2): 260–70. doi:10.1016/j.jenvrad.2007.07.016. PMID 17904707.
[106] Boyd, R. N.; Kajino, T. (1989). "Can Be-9 provide a test of cosmological theories?". The Astrophysical Journal 336: L55. Bibcode:1989ApJ...336L..55B. doi:10.1086/185360.
[107] Dye, J. L. (1979). "Compounds of Alkali Metal Anions". Angewandte Chemie International Edition 18 (8): 587–598. doi:10.1002/anie.197905871.
[108] James, A. M.; Lord, M. P. (1992). Macmillan's chemical and physical data. London: Macmillan. ISBN 0-333-51167-0.
[109] Holleman, Arnold F.; Wiberg, Egon; Wiberg, Nils (1985). "Potassium". Lehrbuch der Anorganischen Chemie (in German) (91–100 ed.). Walter de Gruyter. ISBN 3-11-007511-3.
[110] Lincoln, S. F.; Richens, D. T. and Sykes, A. G. "Metal Aqua Ions" in J. A. McCleverty and T. J. Meyer (eds.) Comprehensive Coordination Chemistry II, Vol. 1, pp. 515–555, ISBN 978-0-08-043748-4.
[111] Georges, Audi; Bersillon, O.; Blachot, J.; Wapstra, A.H. (2003). "The NUBASE Evaluation of Nuclear and Decay Properties". Nuclear Physics A (Atomic Mass Data Center) 729: 3–128. Bibcode:2003NuPhA.729....3A. doi:10.1016/j.nuclphysa.2003.11.001.
[112] Bowen, Robert; Attendorn, H. G. (1988). "Theory and Assumptions in Potassium–Argon Dating". Isotopes in the Earth Sciences. Springer. pp. 203–208. ISBN 978-0-412-53710-3.
[113] "Ruthenium: ruthenium(I) fluoride compound data". OpenMOPAC.net. Retrieved 2007-12-10.
[114] Emsley, J. (2003). "Ruthenium". Nature's Building Blocks: An A-Z Guide to the Elements. Oxford, England, UK: Oxford University Press. pp. 368–370. ISBN 0-19-850340-7.
[115] Harris, Donald C.; Cabri, L. J. (1973). "The nomenclature of the natural alloys of osmium, iridium and ruthenium based on new compositional data of alloys from world-wide occurrences". The Canadian Mineralogist 12 (2): 104–112.
[116] "WWW Table of Radioactive Isotopes". Lawrence Berkeley National Laboratory, Berkeley, US.
[117] "U.S. to pump money into nuke stockpile, increase security," RIA Novosti 18 February 2010
[118] "Uranium". The McGraw-Hill Science and Technology Encyclopedia (5th ed.). The McGraw-Hill Companies, Inc. ISBN 0-07-142957-3.
[119] Hammond, C. R. (2000). The Elements, in Handbook of Chemistry and Physics 81st edition. CRC press. ISBN 0-8493-0481-4.
[120] "uranium". Columbia Electronic Encyclopedia (6th ed.). Columbia University Press.
[121] "uranium". Encyclopedia of Espionage, Intelligence, and Security. The Gale Group, Inc.
[122] Rollett, A. D. (2008). Applications of Texture Analysis. John Wiley and Sons. p. 108. ISBN 0-470-40835-9.
[123] Emsley 2001, p. 480.
[124] "Nuclear Weapon Design". Federation of American Scientists. 1998. Retrieved 19 February 2007.
[125] "Dial R for radioactive – 12 July 1997 – New Scientist". Newscientist.com. Retrieved 12 September 2008.
[126] "Uranium Containing Dentures (ca. 1960s, 1970s)". Health Physics Historical Instrumentation Museum Collection. Oak Ridge Associated Universities. 1999. Retrieved 2013-10-09.
[127] "Oklo: Natural Nuclear Reactors". Office of Civilian Radioactive Waste Management. Archived from the original on 3 June 2004. Retrieved 28 June 2006.
[128] Pallmer, P.G.; Chikalla, T.D. (1971). "The crystal structure of promethium". Journal of the Less Common Metals 24 (3): 233. doi:10.1016/0022-5088(71)90101-9.
[129] Gschneidner, K.A., Jr. (2005). "Physical Properties of the rare earth metals". In Lide, D. R. CRC Handbook of Chemistry and Physics (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.
[130] Chikalla, T. D.; McNeilly, C. E.; Roberts, F. P. (1972). "Polymorphic Modifications of Pm2O3". Journal of the American Ceramic Society 55 (8): 428. doi:10.1111/j.1151-2916.1972.tb11329.x.
[131] Cotton, Simon (2006). Lanthanide And Actinide Chemistry. John Wiley & Sons. p. 117. ISBN 978-0-470-01006-8.
[132] G. Audi, A. H. Wapstra, C. Thibault, J. Blachot and O. Bersillon (2003). "The NUBASE evaluation of nuclear and decay properties". Nuclear Physics A 729 (1): 3–128. Bibcode:2003NuPhA.729....3A. doi:10.1016/j.nuclphysa.2003.11.001.
[133] Hammond, C. R. (2011). "Prometium in "The Elements"". In Haynes, William M. CRC Handbook of Chemistry and Physics (92nd ed.). CRC Press. p. 4.28. ISBN 1439855110.