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RESEARCH ARTICLE

The Rutherford-Harkins-Landau-Chadwick Key–I. Introduction to Nuclear Chemistry

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ABSTRACT

For organic chemistry, Kekulè´s theory of the structure of benzene provided dramatic new clarity of understanding and a reliable guide to both analytic and synthetic studies. The field of organic chemistry developed explosively from this point. Many new models of atomic nuclei have been developed during the last hundred years, and they have advantages and disadvantages. However, no nucleus model based on unorganized structures of protons (usually depicted as red balls) and neutrons (usually depicted as blue balls) can offer a simple predictive model to describe and predict the results of fusion and fission reactions. Many experimental data in nuclear physics during the past century should be newly organized. Is it possible to discover a hidden key that opens doors to a deeper understanding of events occurring in the femtometer size scales? In our model, we propose returning to the bifurcation point in nuclear physics that Pauli and Fermi determined with their neutron and neutrino model in 1934. Based on the classical nuclei models proposed by Old Masters–Rutherford, Harkins, Landau, and Chadwick-before the year 1934, we attempt to further develop their models based on the compound neutron (the composition of proton and electron). Several basic rules for the nuclear structure were postulated, leading to a new view of the world of nuclei. The potential of this model will be documented in three interconnected papers.

Keywords: Bifurcation point in 1934, compound neutron, nuclear chemistry, Rutherford-Harkins-Landau-Chadwick key.

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1. INTRODUCTION

Over decades, numerous nuclei models have been developed to describe atomic nuclei's complex structure and behavior. Each model provides unique insights and significantly contributes to our understanding of nuclear physics. However, they also come with inherent limitations e.g., [1]–[10]. These established models collectively paint a comprehensive picture of nuclear structure and interactions, yet they leave gaps in our understanding. Given the complexity and vastness of nuclear interactions, unexplored pathways and principles to model nuclei may still exist. Machine learning applied to nuclear physics offers a new way to extend our knowledge about nuclear reactions e.g., [11]–[20].

On the other hand, we can search for inspiration in the works of the Old Masters. There exists a significant bifurcation point in the history of nuclear physics: Pauli and Fermi formulated the neutron and neutrino models in 1934 [21] and effectively closed the development of older models based on the compound neutron (the composition of proton and electron). In the historical literature published by the founding fathers of nuclear physics before 1934, we can rediscover a hidden key leading to a new view into the events occurring during fusion and fission reactions e.g., [22]–[23]. This lost key, forgotten in old literature and published in the field of nuclear physics before the year 1934, might interpret events in the femtometer size scales from a deeper perspective. In this model, we can rewrite all fusion and fission reactions and tune the rules based on numerous known nuclear reactions. The discovery of rules determining the composition of nuclei might guide us on how to design some new unknown nuclear reactions.

2. THE LOST AND FORGOTTEN KEY IN NUCLEAR PHYSICS

The historical literature in nuclear physics can offer readers many inspirational ideas. In 1920, Ernest Rutherford [24] modeled the helium nucleus as the composition of four hydrogen and two negative electrons with a resultant plus two charges. In his models of nuclei, one electron can bind three protons, two protons, or one proton. Electrons in the nuclei always have a total of three bounds. In this Bakerian lecture, Rutherford predicted the existence of neutron and helium-3 and proposed models of several nuclei.

William D. Harkins, during the period of 1915–1936 e.g., [25]–[27], published many papers where he proposed the composition of known nuclei known in his time as the collection of subunits (written in modern nomenclature):

$$subunits: \ {}^{4}_{2}He, {}^{1}_{1}H, {}^{2}_{1}H, {}^{3}_{1}H, {}^{1}_{0}n, {}^{2}_{0}n, {}^{3}_{0}n, {}^{4}_{0}n \tag{1}$$

Harkins described all known isotopes in his time as the composition of sub-units. For example:

$$compound\,nuclei: \ {}^{6}_{3}Li = \left[{}^{4}_{2}He + {}^{2}_{1}H\right] \ {}^{7}_{3}Li = \left[{}^{4}_{2}He + {}^{3}_{1}H\right] \tag{2}$$

$$compound\,nuclei: \ {}^{35}_{17}Cl = \left[8 \times {}^{4}_{2}He + {}^{3}_{1}H\right] \ {}^{37}_{17}Cl = \left[8 \times {}^{4}_{2}He + {}^{3}_{1}H + {}^{2}_{0}n\right] \tag{3}$$

Roger H. Stuever [28] evaluated Harkins' contribution to nuclear physics: "The Chicago physical chemist W. D. Harkins began a program in 1915 of numerical speculation on isotopic structures seldom equaled in the history of science. Helge Kragh [29] described the Harkins method: "In lengthy and rather speculative papers in Physical Review and Journal of the American Chemical Society, Harkins argued that atomic nuclei consisted mainly of hydrogen and helium nuclei, meaning protons and alpha particles".

Lev D. Landau, in 1932, proposed [30]–[32] the existence of a gigantic nucleus composed of neutrons: "Indeed we have always protons and electrons in atomic nuclei very close together, and they do not annihilate themselves".

James Chadwick, in 1932, discovered the neutron and interpreted this particle as the compound of proton and neutron [33]. In our model termed the Rutherford-Harkins-Landau-Chadwick Key, we will depict nuclei as the ring of alpha particles with attached subunits given in (1). Several rules describing the structure of nuclei as the composition of protons and electrons based on the known fusion and fission reactions can be postulated as:

1. Electrons in stable nuclei always have three bonds with protons.
2. Electron in unstable proton-rich nuclei has four bonds with protons; during the electron capture, one proton converts into a neutron attached to the ring.
3. Proton has three, two, or one bonds with electrons–it depends on the context of that situation.
4. The nucleus ring comprises a polymer of open alpha particles: - [alpha]$_{x}$-.
5. During alpha decay, one alpha unit is released from the ring to decrease the rotational energy of that nucleus (alpha decay).
6. The attached subunit dineutron in the neutron-rich nuclei can release one electron–the beta decay–and the subunit deuteron is formed. The energy is shared between the formed electron and the nucleus's rotational energy (β- decay). (No need for the neutrino postulate).
7. The attached subunit deuteron can capture one electron by forming one dineutron attached to the ring. Two γ rays are formed simultaneously in opposite directions ("β+ emission").
8. In unstable proton-rich nuclei, the subunit deuteron can absorb one electron under the formation of two neutrons–both attached to the ring (EC-electron capture).
9. The alpha particle hitting a nucleus can release a neutron from that nucleus (neutron emission).
10. Several unique reactions occur on the nucleus ring, e.g., on the ring of the nucleus C-12, one alpha particle can grow in several steps (this reaction is known as the Bethe-Weizsäcker CNO cycle). This is one example of the epitaxial growth on the nucleus ring.

During the fusion and fission reactions, the rotational energy of formed nuclei decreases, and nuclear physicists can observe and apply the released energy.

3. PROPOSED NUCLEAR STRUCTURES OF SOME SMALL NUCLEI

The rules above can be used to construct all possible known isotopes proposed by the Harkins program. Figs. 1 and 2 show several small nuclei.

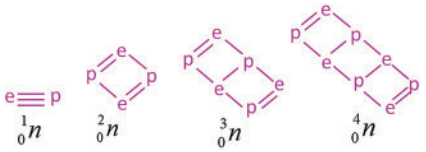


Fig. 1. Proposed structures for neutron, dineutron, trineutron, and tetraneutron. The magenta color depicts the neutron structure.

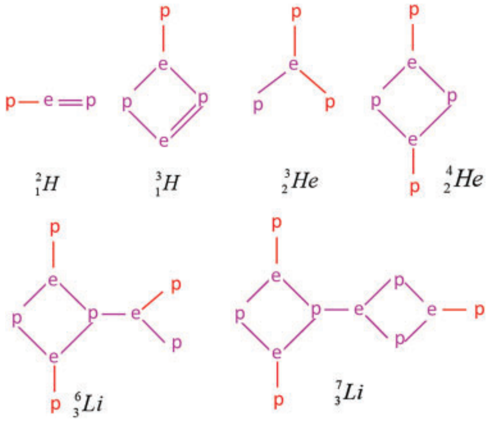
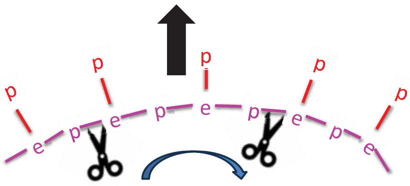


Fig. 2. Proposed structures of some light nuclei. The magenta color depicts the neutron structure, the red color depicts the proton structure.



$$ALPHA\ DECAY: {}^A_ZX \Rightarrow {}^{A-4}_{Z-2}Y + {}^4_2He$$

Fig. 3. The proposed model of the alpha decay reaction from the rotating nucleus to decrease the parent nucleus's rotational energy through the emission of alpha particles in the perpendicular direction (monoenergetic reaction)–the reversed cycle addition.

4. Proposed Basic Nuclear Reactions

The rules given above can be used to construct some basic nuclear reactions. In this model, the alpha particle emitted from a nucleus has to overcome the Coulomb barrier given by the circular ring charge density $\lambda = Ze/(2\pi R)$. The radius of the ring can be approximated as $R = Z/\pi$, where Z is the proton number, and the size of the neutron is approximated as 1 femtometer:

$$E_{out} = \frac{e^2}{4\pi\varepsilon_0}2\lambda = \frac{e^2}{4\pi\varepsilon_0}\frac{2Z}{2\pi R} = 1.44\frac{2Z}{2\pi}\frac{\pi}{Z} \approx 1.44\,[MeV] \tag{4}$$

On the other hand, the alpha particle flying from outside to the nucleus ring, has to overcome a higher Coulomb barrier:

$$E_{in} = \frac{e^2}{4\pi\varepsilon_0}\frac{2Z}{R} = 1.44\frac{2Z}{1}\frac{\pi}{Z} \approx 1.44 \times 2\pi \approx 9.0\,[MeV] \tag{5}$$

The paradox of the alpha particle emission and absorption explained Gamow [34] and independently Gurney with Condon [35] by their famous model of the "quantum tunnelling". In our model of the circular ring, it is easier for the alpha particle to escape from the nucleus than to enter back from outside. Therefore, it is necessary to apply alpha particles with higher energy than 9.0 MeV in order to penetrate from outside through the Coulomb barrier. Fig. 3 shows the alpha decay process. This nucleus reaction can be termed as the reversed cycle addition.

Another very important nuclear reaction is the beta decay β- from the dineutron attached to the nucleus ring shown in Fig. 4. The observed mysterious spectrum of energy of released electrons [36], [37] is interpreted in this model as the sharing of the rotational energy of the parent nucleus with the energy of released electron which depends on the emission angle of that electron from the rotating parent nucleus.

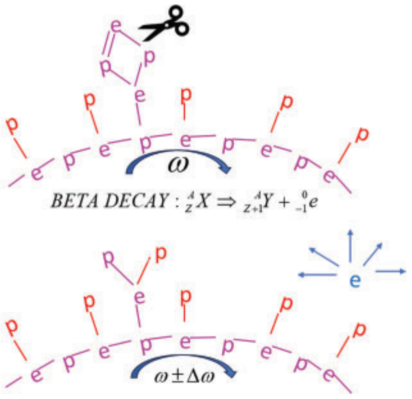


Fig. 4. Proposed beta decay reaction from the rotating nucleus: dineutron loses one electron sharing energy with the rotating nucleus, where the missing energy is hidden in the rotational energy of that parent nucleus (poly energetic reaction without the postulation of neutrino).

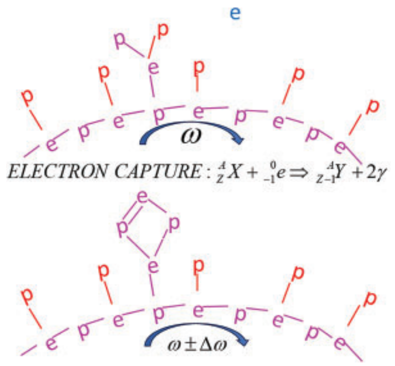


Fig. 5. Proposed model of the positron emission β^{+}: electron is captured by the deuteron under the formation of the dineutron and two simultaneous emissions of γ rays in opposite directions are observed, no "positron emission" is needed.

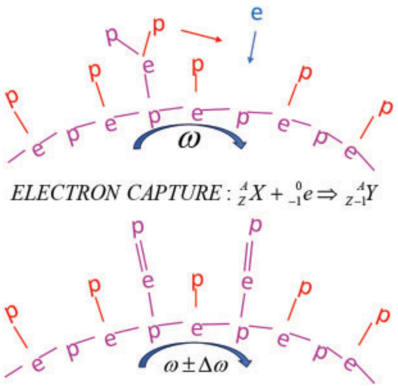


Fig. 6. Proposed model of the electron capture EC: electron is captured by the deuteron under the formation of two separated neutrons attached separately to the nucleus ring.

The inverse nuclear reaction of the electron capture by the deuteron followed by the emission of two γ rays is described as the positron emission $\beta+$. During this nuclear reaction, the electron is captured by two protons in the deuteron unit. The electron is temporarily hidden ("annihilated") in the dineutron structure; later, under some conditions, this electron can be released again. This reaction is shown in Fig. 5.

There is possibly another nuclear reaction of the electron capture (termed as the EC) by the deuteron sub-unit followed by the formation of two neutrons, both attached separately to the ring of the parent nucleus. This reaction is shown in Fig. 6.

5. Three Examples of Nuclear Reactions

The founding father of nuclear physics, Ernest Rutherford, fulfilled the dream of old alchymists' and realized the transmutation of nitrogen-14 into oxygen-17 [38] (depicted in Fig. 7). (During this nuclear reaction, the decay energy of alpha particles formed from the metastable polonium-214 to

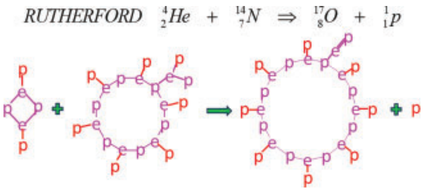


Fig. 7. Rutherford´s transmutation reaction–the cycle addition of alpha particle.

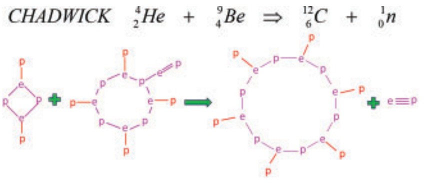


Fig. 8. Chadwick´s discovery of neutron: The cycle addition of alpha particle.

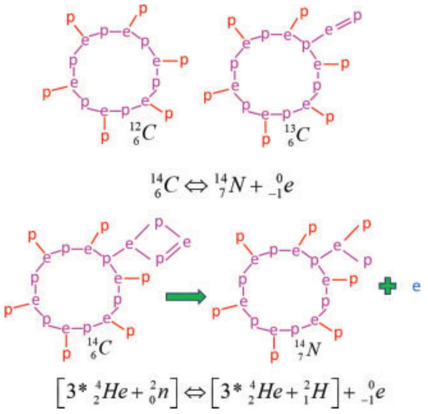


Fig. 9. Isotopes of C-12, C-13, and C-14. Beta decay of C-14 is written in the Harkins´ notation.

lead-210 was 9.248 MeV). Alpha particles penetrated through the Coulomb barrier of nitrogen and were incorporated into the nucleus ring–the reaction termed cycle addition. The deuteron sub-unit was decomposed into the neutron attached to the resulting nucleus ring and one free proton.

James Chadwick, in 1932, discovered the particle neutron and interpreted that particle as a compound of proton and neutron [39]. Chadwick irradiated beryllium-9 with alpha particles formed from polonium-214 with an energy of 9.248 MeV. Alpha particle penetrated through the Coulomb barrier of beryllium-9 to the site where the sub-unit particle neutron was already attached. The beryllium ring was opened at this "active site," and an alpha particle was inserted into the ring structure under the formation of carbon-12–the example of the nucleus reaction termed the cycle addition. The sub-unit neutron was released from the final nucleus structure. This nuclear reaction is shown in Fig. 8.

There are three naturally occurring isotopes of carbon on Earth: carbon-12, carbon-13, and carbon-14. Martin Kamen and Samuel Ruben discovered Carbon-14 on February 27, 1940. Willard Libby developed the concept of radiocarbon dating in 1945 [40]. Carbon-14 is unstable and decays into nitrogen-14 through beta decay. We can write this reaction in three different ways: in the standard nomenclature, in the style of nuclear chemistry, and the Harkins´ nomenclature–see Fig. 9. In this nuclear reaction, the sub-unit dineutron is converted into deuteron. At the same time, the electron escapes from the resulting structure.

6. One example of the Cycle Formation during Nuclear Reactions–Triple-Alpha Process

Many nuclear reactions exist where linear nuclei can form a ring structure. The very famous nuclear reaction is the triple-alpha reaction, where three linear alpha particles form the ring structure of carbon-12. The nuclear fusion reaction of two linear helium-4 nuclei produces beryllium-8, which is unstable and decays back. However, within a short time, a third alpha particle can fuse with the beryllium-8 nucleus to produce an excited resonance state of linear carbon-12, called the Hoyle state [41], which nearly always decays back into three alpha particles, but in few cases can be stabilized in the ring structure of carbon-12.

Fig. 10 presents this cycle formation from linear chain chains of alpha particles.

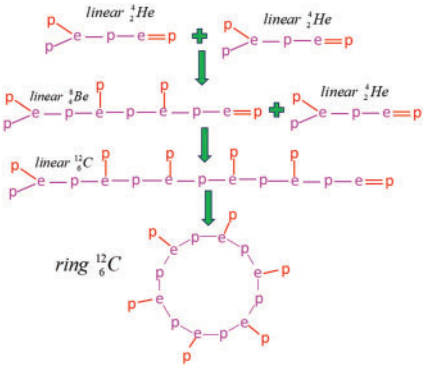


Fig. 10. Triple alpha cycle: formation of one ring from three linear chains. Three linear alpha particles fuse together to form the stable ring of carbon-12.

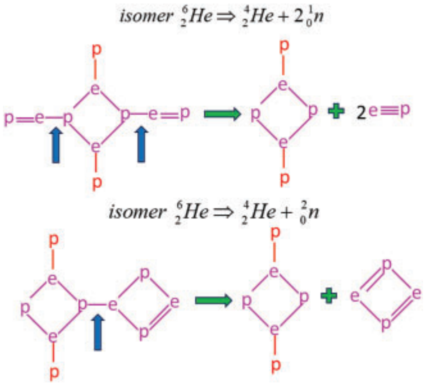


Fig. 11. Two nuclear reactions of isomers of the nucleus helium-6 with the formation of two neutrons or the formation of one dineutron.

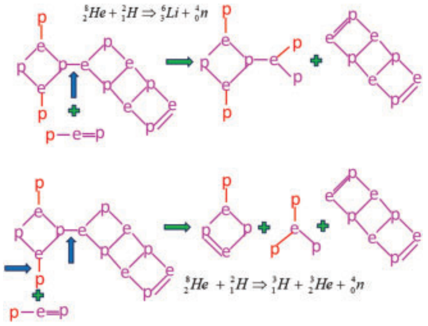


Fig. 12. Tetraneutron formation form the decomposition of the nucleus helium 8.

7. Nuclear Reactions of Isomer Nuclei (Borromean Nuclei [42], [43])

Isomer nuclei exist with the same proton and neutron numbers. They might differ in the internal structure of neutrons as predicted by Harkins–neutron, dineutron, trineutron, and tetraneutron. Fig. 11 compares the nuclear reactions of two isomers of the nucleus helium-6.

8. Population of Tetraneutron Continuum in Reactions of Helium-8 on Deuteron [44]

The search for multi-neutron systems is old, but it is still an unsettled problem in nuclear physics. A detailed account of the history of multi-neutron studies, both experimental and theoretical, was recently provided [45]. Fig. 12 shows a schema of the tetraneutron formation from the nucleus helium-8 on deuteron.

9. Moment of Inertia and Rotational Kinetic Energy of Rotating Nuclei

Energy in rotational motion is the energy associated with rotational motion, the same as kinetic energy in translation motion. The kinetic energy of a rotating object is expressed via its translational velocity v_t, angular velocity ω, the distance R of the particle from the axis of rotation, and the moment

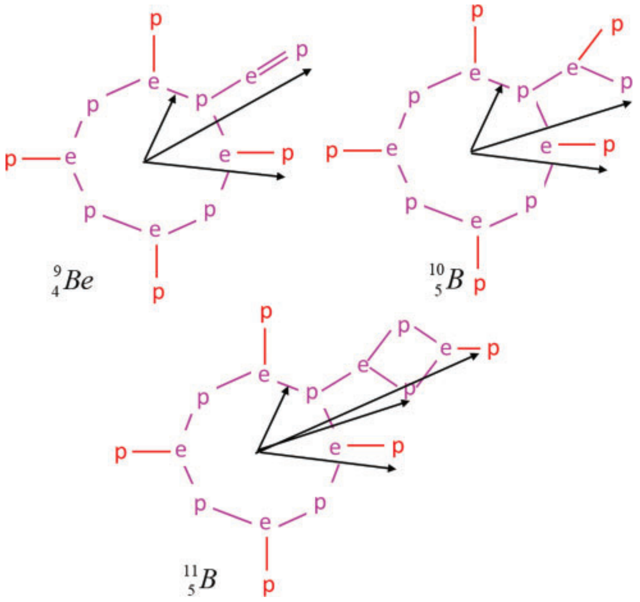


Fig. 13. Determination of the moment inertia for some nuclei.

of inertia I around the axis of rotation:

$$K = \frac{1}{2} m v_t^2 = \frac{1}{2} m (\omega R)^2 = \frac{1}{2} \left(m R^2 \right) \omega^2 = \frac{1}{2} I \omega^2 \tag{6}$$

For the case of rotating nuclei (the mass of proton and neutron is approximately 1 amu-atomic mass unit, and the size of the neutron is approximated as 1 femtometer), the radius of the ring is approximately $R = Z/\pi$. We propose that the nuclear binding energy can be interpreted as the change in the rotational energy caused by the change of angular velocity of the parent nucleus after the nuclear reaction:

$$BE = \frac{1}{2} I (\Delta\omega)^2 = \frac{1}{2} \left(\sum_j m_j R_j^2 \right) (\Delta\omega)^2 \tag{7}$$

Therefore, the missing energy in nuclear reactions (as in the beta decay) should be hidden in the change of the rotational energy of the parent nucleus. Fig. 13 depicts how to calculate the moment of inertia for several nuclei.

10. Conclusion

This contribution is based on the works of the founders of nuclear physics–Rutherford, Harkins, Landau, and Chadwick-who published their nucleus models before the bifurcation point defined by the neutron and neutrino models of Pauli and Fermi in 1934.

1. We have postulated rules for describing nucleus structures based on the compound neutron (the compound of proton and electron).
2. Examples of nuclear structures of several small nuclei were documented.
3. Examples of several very well-known nuclear reactions were presented in this novel nucleus nomenclature.
4. The typical nuclear reactions such as alpha decay, beta decay, electron capture, “positron emission,” neutron emission, isomer reactions, and cycle additions were newly interpreted.
5. This nucleus nomenclature rediscovered from works of Old Masters might bring a new view into atomic nuclei’s femtometer size scales and guide us to some new fission and fusion reactions.
6. The new terminology of nuclear chemistry should be developed.
7. Creating software for drawing these nucleus models and nuclear reactions will be very useful, as done in organic chemistry.

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Conflict of Interest

The author declares that there is no conflict of interest.

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