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RESEARCH ARTICLE

The Rutherford-Harkins-Landau-Chadwick Key–III. Fission Interpreted by Nuclear Chemistry

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ABSTRACT

Throughout the past century, scientists introduced various models of atomic nuclei, each bringing unique insights yet burdened with inherent limitations. Despite their contributions, no existing model–visualizing protons as red spheres and neutrons as blue–has provided a straightforward framework to predict or explain the outcomes of fusion and fission reactions. A wealth of experimental data gathered over decades in nuclear physics calls for a renewed organization and interpretation. Might there be a hidden principle, a key that unlocks a profound understanding of the phenomena occurring within femtometer dimensions? This work seeks to revisit the turning point in nuclear physics defined by Pauli and Fermi's neutron and neutrino theory in 1934. We draw inspiration from earlier nuclear models developed by great visionaries such as Rutherford, Harkins, Landau, and Chadwick. Their pre-1934 theories offer a foundation for reexamining the nucleus as the composition of protons and neutrons composed from a proton and an electron. We introduce a set of guiding principles for nuclear structure, which reimagine how the nucleus operates and interacts. This revised perspective offers a gateway to reevaluating long-standing assumptions and forging new insights into nuclear behavior. The implications of this model will be demonstrated across three interconnected papers, each contributing to a more comprehensive view of the nuclear world.

Keywords: Compound neutron, fission reactions, nuclear chemistry, Rutherford-Harkins-Landau-Chadwick key.

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1. INTRODUCTION

Over decades, a wide array of models has been proposed to explain the intricate structure and dynamics of atomic nuclei. These models have significantly advanced nuclear physics by offering unique perspectives, yet each is constrained by inherent limitations, as noted in [1]–[10]. Together, they provide a fragmented but valuable picture of nuclear interactions, leaving unanswered questions and areas ripe for exploration. Given the vast and complex nature of nuclear phenomena, it is likely that untapped principles and uncharted approaches to modeling still await discovery. Emerging methodologies, such as the integration of machine learning into nuclear physics, open new avenues for expanding our knowledge of nuclear reactions, as demonstrated in [11]–[20].

At the same time, there is merit in revisiting the early works of the founding fathers of nuclear physics. A defining moment in nuclear physics occurred in 1934 when Pauli and Fermi introduced their theories of the neutron and neutrino [21], steering the discipline away from earlier models that described the neutron as a compound of a proton and an electron. These earlier frameworks, developed by the pioneers of nuclear physics prior to 1934, may hold a forgotten key–a pathway to reinterpreting the fusion and fission process [22], [23].

This overlooked key, embedded in pre-1934 literature, provides an opportunity to examine events at femtometer scales from a renewed perspective. By reanalyzing known fusion and fission reactions and refining the underlying principles of nuclear composition, we aim to uncover systematic rules that could illuminate the mechanism governing nuclei. These discoveries may not only enhance our understanding

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of existing reactions but also guide the design of entirely new nuclear processes, bridging historical insights with modern scientific advancement.

2. The Lost and Forgotten Key in Nuclear Physics

The historical literature in the field of nuclear physics can offer readers many inspirative forgotten ideas: some are outdated, and some might offer a big surprise. For example, Rutherford [24], in numerous papers, modeled the helium nucleus as the composition of four hydrogen and two negative electrons with a resultant charge of plus two. In his composite nuclei, one electron can bind three protons, two protons, or one proton. Electrons in stable nuclei always have a total of three bounds. Rutherford predicted the existence of neutron and helium-3 and proposed models of several nuclei in his Bakerian lecture in 1920.

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

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

Harkins proposed to express nuclei and their known isotopes as the composition of sub-units, e.g.,:

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

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

Unfortunately, these contributions of Harking were soon forgotten, and only a few historians of nuclear physics mentioned their existence. For example, Stuever [23] evaluated Harkins' contribution to nuclear physics as follows: "The Chicago physical chemist W.D. Harkins in 1915 began a program of numerical speculation on isotopic structures seldom equaled in the history of science."

Kragh [28] described the Harkins method as follows: "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 [29]–[31] 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." However, the actual existing models cannot explain a possible structure of poly-neutron nuclei.

James Chadwick, in 1932, discovered the neutron and interpreted this particle as the compound of proton and neutron [32]. In 1934, Fermi converted the community of nuclear physics in favor of his neutron and neutrino theory.

Based on the old models formulated by Rutherford, Harkins, Landau, and Chadwick before the critical year 1934, we will define the Rutherford-Harkins-Landau-Chadwick Key, where nuclei are formed from rings of alpha particles with attached subunits given in (1), (2) and (3). 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. An electron in stable nuclei always has three bonds with protons.
2. An electron in unstable proton-rich nuclei has four bonds with protons. During electron capture, one proton converts into a neutron that is 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 is composed of a polymer of open alpha particles: - $[\text{alpha}]_x$-.
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 energy of the formed electron and the rotational energy of the parent nucleus (β^- decay). (No need for the neutrino postulate).
7. The attached subunit deuteron can capture one electron under the formation of 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.
11. During the fusion and fission reactions, the rotational energy of formed nuclei decreases, and the released energy can be observed and applied by nuclear physicists.

3. THE BINDING ENERGY OF NUCLEI INTERPRETED AS THE CHANGE OF THEIR ROTATIONAL ENERGY

Fission has a unique importance among nuclear reactions with its profound impact on the affairs of man. While we understand many aspects of the fission process, there is no overall theoretical framework that gives a satisfactory account of the basic observations, e.g., [33]–[39]. Therefore, we should try to develop some new models of nuclei in order to penetrate to a deeper level of events on the femtometer size scales.

In our model of the rotating nuclear ring, we can describe the rotational kinetic energy $KE_{rotational}$ as:

$$KE_{rotational} = \frac{1}{2} I \omega^2 \tag{4}$$

where I is the moment of inertia, and ω is the angular velocity. We assume that the experimentally measured binding energy BE of nuclei evaluates the change in the rotational kinetic energy of rotating nuclei:

$$BE_{rotational} = \frac{1}{2} I \left(\Delta\omega\right)^2 = \frac{1}{2} \sum\nolimits_j m_j r_j^2 \left(\Delta\omega\right)^2 \tag{5}$$

where $m_j \approx 1$ amu (atomic mass unit sometimes termed as Dalton) is the mass of protons and neutrons contained on that rotating ring, r_j is the distance of protons from the center of that ring, the size of the neutron is approximately $\approx$1 fm, and therefore the radius R of that ring can be approximated as $R \approx Z/\pi$ (Z is the proton number of that nucleus). Fig. 1 shows a schema for the determination of the moment inertia of some nuclei.

The moment of inertia per nucleon I/A where A is the atomic mass is calculated as:

$$\frac{I}{A} = \frac{\sum_j m_j r_j^2}{A} \qquad \left[amu\, fm^2\, amu^{-1}\right] \tag{6}$$

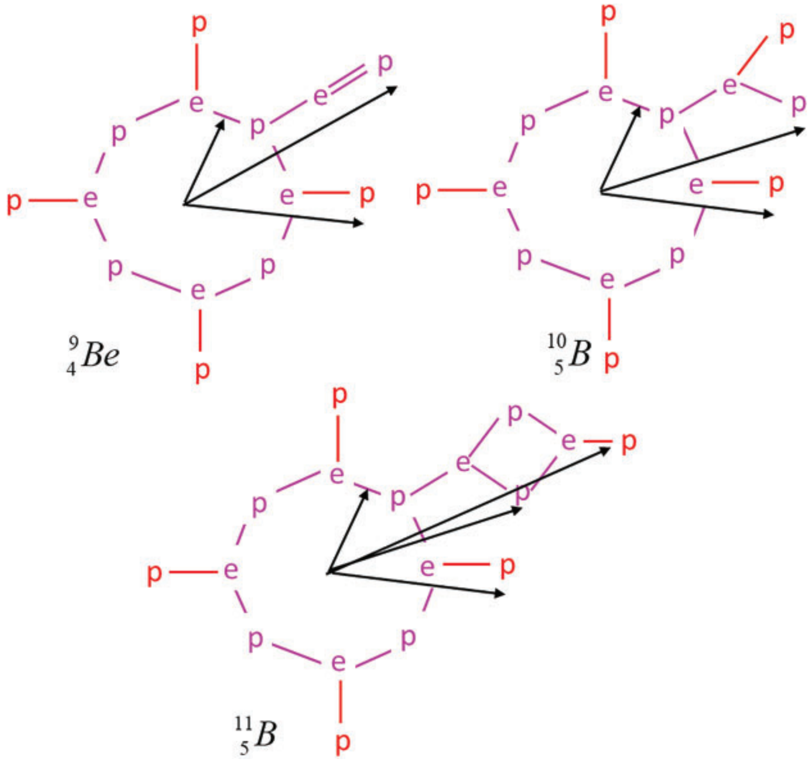

Fig. 1. Determination of the moment of inertia of a nucleus, mass of proton $\approx$ 1 amu, radius of that ring $R \approx Z//\pi$, Z is the proton number of that nucleus, the size of a neutron is approximately 1 fm.

Fig. 2 shows the values of the moment of inertia per nucleon for some stable nuclei.

Fig. 3 depicts the change of the angular orbital velocity calculated from (5).

The change in orbital velocity calculated as the ratio v/c depends on the radius R of the rotating nucleus and reveals a minimum near the nucleus iron-56. This situation is given in Fig. 4.

It has to be noted that our calculation is done as a first approximate evaluation of this approach. The more precise calculation of the moment of inertia of nuclei should apply with a more precise size of the neutron contained in the ring and neutrons attached to the ring.

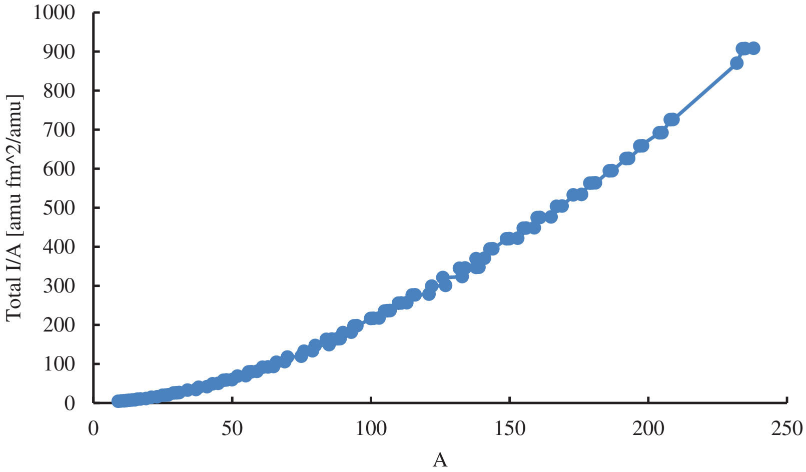

Fig. 2. The moment of inertia per nucleon for some stable nuclei.

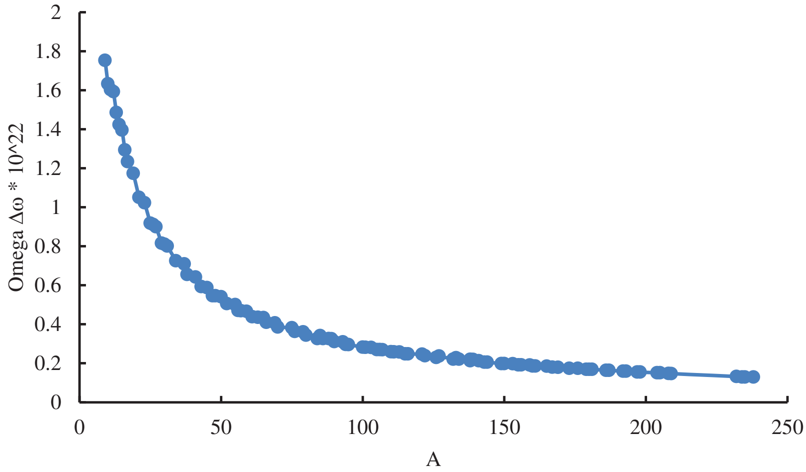

Fig. 3. Change of the angular velocity of rotating some stable nuclei calculated from (5).

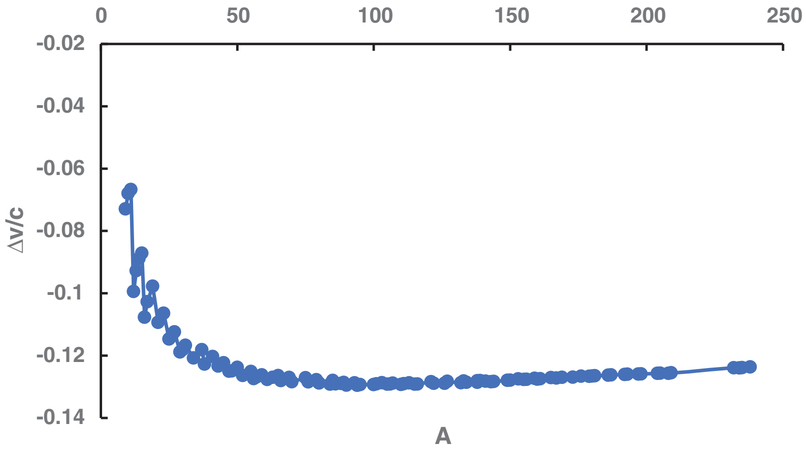

Fig. 4. Change in orbital velocity of some stable rotating nuclei expressed as the ratio Δv/c.

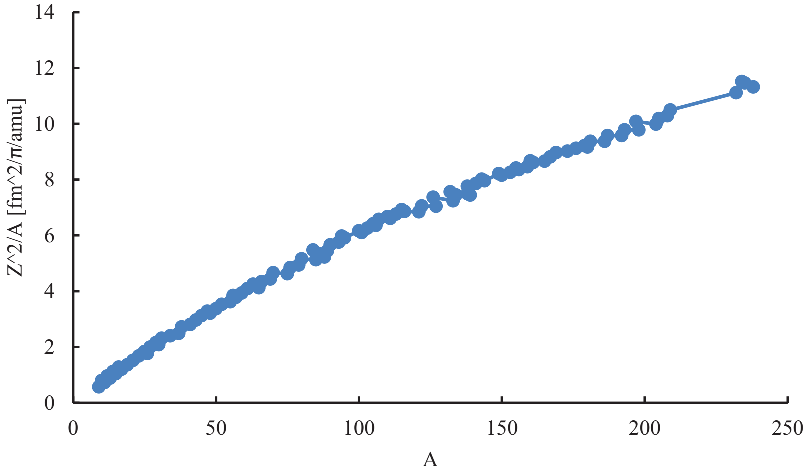

Fig. 5. The ratio of ring area of nuclei to their mass. The first possible interpretation of the fissility parameter.

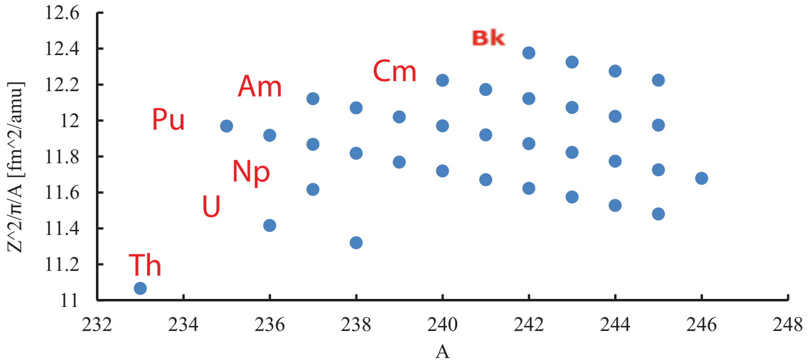

Fig. 6. The ratio of the ring area of nuclei to their mass for the known spontaneously fissioning isomers.

During the analysis of fission reactions, many researchers found that the ratio Z^2/A reveals important information about the stability of nuclei [40]. This ratio term, the fissility parameter, was derived from the nucleus' liquid-drop model. In our model, we propose two possible new interpretations of this empirical parameter. The first interpretation describes the fissility parameter as the ratio of the inner area of that nucleus ring and the mass of the nucleon:

$$\frac{ringarea}{mass} = \frac{\pi R^2}{A} \approx \frac{\pi\left(\frac{Z}{\pi}\right)^2}{A} = \frac{Z^2}{\pi A} \tag{7}$$

Fig. 5 brings new information about the stability of nuclei: when the ratio of the ring area to the mass of nucleon exceeds a certain critical value, then the nucleon will be spontaneously fissile.

Fig. 6 gives a detailed picture of the ratio of ring area to the mass of the known spontaneously fissioning isomers. The first possible interpretation of the fissility parameter.

The following Fig. 7 brings information about the ratio of the moment of inertia to the mass of the known spontaneously fissioning isomers of plutonium-94. This is the second possible interpretation of the fissility parameter based on (5). For the calculation of the moment of inertia, we have assumed that the ring consists of 94 neutrons, and the protons and remaining neutrons are attached to the ring. The structure of that ring is composed of 47 alpha particles: -[alpha]$_{47}$-.

4. Decrease of the Moment of Inertia During Spontaneous Nuclear Reactions

We can evaluate the change in the moment of inertia between the parent and daughter nuclei. In the first approach, we can use a simple (8):

$$I \approx A\left(\frac{Z}{\pi}\right)^2 \quad [amu\, fm^2] \tag{8}$$

For the case of the alpha decay of polonium-210 to lead-206:

$${}^{210}_{84}Po \Rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He \tag{9}$$

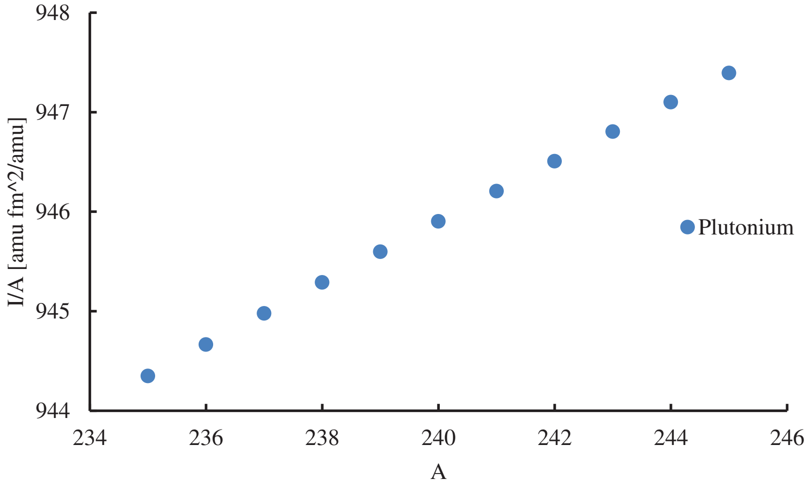

Fig. 7. The ratio of the moment of inertia to the mass of spontaneously fissioning isomers of plutonium-94.

the change of the moment of inertia between these two nuclei equals:

$$\Delta I = I_{Po} - I_{Pb} \approx 1 * 10^4 \ \left[amu\, fm^2\right] \tag{10}$$

The spontaneous fission of uranium-235 can be written as:

$$ {}^{235}_{92}U + {}^{1}_{0}n \Rightarrow {}^{132}_{50}Sn + {}^{100}_{42}Mo + 4\,{}^{1}_{0}n \tag{11}$$

and the change of the moment of inertia between these three nuclei equals:

$$\Delta I = I_U - I_{Sn} - I_{Mo} \approx 15 * 10^4 \ \left[amu\, fm^2\right] \tag{12}$$

5. FORMATION OF THE SCISSION POINT ON THE RING OF A BIG NUCLEUS

Many mechanisms for the fission of big nuclei were proposed, e.g., [41]–[51]. All these proposals try to guess a possible scenario of this important event in the femtometer size scales. We propose a new mechanism of fission based on the creation of the scission point with the local Coulomb repulsion. One example of the appearance of such a scission point on the ring of a big nucleus is the nucleus of plutonium-239:

$$ {}^{238}_{92}U + {}^{1}_{0}n \Rightarrow {}^{239}_{92}U \Rightarrow {}^{239}_{93}Np + {}^{0}_{-1}e \uparrow \Rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}e \uparrow \Rightarrow fission \tag{13}$$

The idea of this mechanism is the existence of two dineutron subunits in a close position followed by two beta decays. Two deuteron subunits were created at a very close distance. The Coulomb repulsion

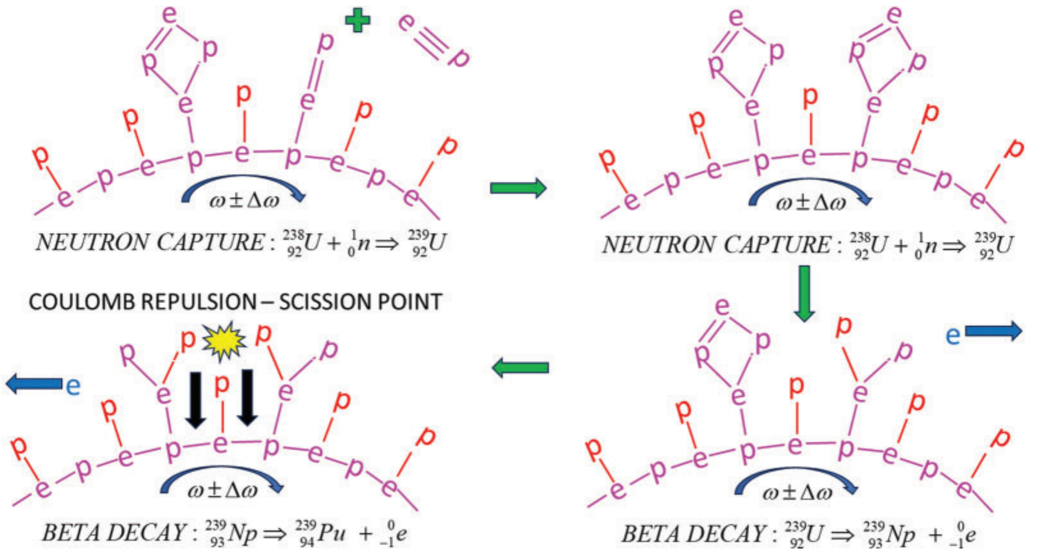

Fig. 8. Proposed scenario for the creation of the scission point with the Coulomb repulsion on the ring of the nucleus plutonium-239.

on that scission point increases the tension in the ring of that big nucleus. The scission point is "activated" and opens the nucleus ring. Two smaller nucleus rings with a lower moment of inertia have been flying apart. This scenario is depicted in Fig. 8.

This contribution is an introduction to the possible description of events occurring in the femtometer size scales. It will be important to tune this model on hundreds of known nuclear reactions. We might be in the same situation as organic chemists were around the year 1860. Once the basic rules valid for the carbon in organic molecules were discovered, the field of organic chemistry exploded from ten thousand known molecules to today's twenty million organic molecules.

6. Conclusion

This contribution is based on the works of the founding fathers 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 the description of nucleus structures based on the compound neutron (the compound of proton and electron).
2. The concept of the moment of inertia for the rotating nuclei was proposed.
3. The binding energy of nuclei was connected with the rotational kinetic energy of nuclei.
4. The spontaneous fission of a parent nucleus proceeds because daughter nuclei decrease the moment of inertia of the parent nucleus.
5. The formation of the scission point with the Coulomb repulsion was proposed for the nucleus plutonium-239.
6. This nucleus nomenclature rediscovered from works of Old Masters might bring a new view into the femtometer size scales of atomic nuclei and guide us to some new fission and fusion reactions.
7. The new terminology of nuclear chemistry should be developed.
8. It will be very useful to create software for drawing these nucleus models and nuclear reactions as it was 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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