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Experimental Correlation of Mercury (Hg) Isotopes with the Alikhan Symmetry-Based Nuclear Stability Model

Alikhan Mammadaliyev

Independent Researcher, Beylagan, Azerbaijan
Email: alikhanmammadaliyev@gmail.com

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Abstract

The study presents a symmetry-based analysis of Mercury (Hg) isotopes (A = 171 - 216) according to the Alikhan structural model. The model interprets nuclear stability as a result of the balance between nuclear attractive forces and Coulomb repulsion within symmetric proton-neutron frameworks. The comparison with experimental half-lives demonstrates a strong correlation between the equatorial neutron balance, nuclear force equilibrium, and isotopic stability. The findings align with the concept of "magic numbers" while refining it through spatial symmetry and stability intervals. This work demonstrates that isotopic stability trends of Mercury can be systematically interpreted through spatial symmetry parameters rather than shell occupation alone, providing a complementary qualitative perspective to conventional nuclear models.

Keywords

Mercury Isotopes, Nuclear Stability, Symmetry-Based Nuclear Model, Proton-Neutron Structure, Equatorial Neutron Balance, Isotopic Half-Life Correlation

1. Introduction

Classical nuclear models such as the shell model, the liquid-drop model, and the "magic number" concept have historically been used to describe nuclear stability [1]-[4].

While these approaches successfully explain many isotopic behaviors, they fail to account for transitional regions, particularly in heavy nuclei such as Mercury (Hg) [3] [5]-[7].

The Alikhan Symmetry Model proposes a complementary framework in which the nucleus is interpreted as a layered proton-neutron structure [5].

In this model, stability emerges from the spatial symmetry between polar and equatorial regions, even-odd neutron parity, and the balance between nuclear attraction and Coulomb repulsion [5].

It should be noted at the outset that the present model is qualitative in nature and is intended to reveal systematic structural correlations rather than provide exact quantitative predictions.

The primary objective of this study is to test the explanatory power of the Alikhan Symmetry Model against experimental half-life data of Hg isotopes across a wide mass range.

2. Methodology

The neutron framework is constructed using symmetrical layers distributed around the equator.

Each layer follows a numeric sequence (1 + 3 + 6 + 9 + 12 + …), representing spatial shells [5], arising from the progressive filling of concentric equatorial layers with increasing circumference, reflecting a simplified geometric growth of nuclear cross-sections.

When the equatorial balance ("Ekvator balansı") equals zero, the nucleus is perfectly symmetric, ensuring stability [5] [8] [9].

In this framework, a value of 0 corresponds to an equal number of neutrons on both sides of the equatorial plane, whereas deviations of ±1 arise when one additional neutron occupies either the upper or lower equatorial-adjacent layer, producing mechanical and energetic asymmetry.

This geometric interpretation does not replace quantum mechanical descriptions but provides a complementary macroscopic symmetry criterion.

A deviation of ±1 introduces mechanical and energetic imbalance, leading to reduced stability [9].

The "stability interval" refers to the range of isotopic compositions where nuclear attraction and Coulomb repulsion reach equilibrium [6].

In practical terms, this interval corresponds to a limited N-Z range in which the equatorial balance remains equal to 0 or fluctuates minimally (±1) without destroying global symmetry.

Deficit ("def") and surplus ("artıq") zones in the N-Z balance define regions of instability [6] [10].

3. Results and Analysis

3.1. Low-Mass Region (A = 171 - 193)

Half-lives range from microseconds to several hours (80 μs - 3.8 h) [6] [10].

This region is dominated by neutron deficit (N-Z = −25 to −3), leading to reduced symmetry and short lifetimes.

The presence of an odd neutron in the equatorial layer introduces a ±1 equatorial balance, creating mechanical asymmetry and further destabilizing the nucleus [9].

As the neutron number increases, the gradual reduction of neutron deficit leads to a steady increase in half-life, indicating partial symmetry restoration.

3.2. Transition Region (A = 193 - 196)

A sharp transition in stability occurs: Hg-193 (3.8 hours) → Hg-194 (444 years) → Hg-196 (stable) [6] [10].

Symmetry restoration (Ekv. Balans = 0) corresponds to equilibrium of nuclear forces [5].

Hg-194 lies near the lower boundary of the stability interval, where nuclear attraction and Coulomb repulsion approach equilibrium.

In contrast, Hg-195 reintroduces an odd equatorial neutron (±1), resulting in a sharp decrease in half-life.

Hg-196 is located at the center of the stability interval, representing a perfectly balanced configuration [5] [9].

3.3. Stability Plateau (A = 198 - 202)

Hg-198, Hg-199, Hg-200, Hg-201, and Hg-202 remain stable despite neutron parity variation [6].

This plateau indicates that force equilibrium dominates over parity deviations [9].

Even in isotopes containing odd neutrons (Hg-199 and Hg-201), global symmetry and force balance are preserved because these nuclei lie well within the stability interval.

Nuclear-Coulomb forces are harmonized, ensuring stability even under minor symmetry imperfections [5].

3.4. Upper Stability Edge (A = 203 - 204)

Transition from Hg-203 (odd N) to Hg-204 (even N) results in a lifetime increase (46.6 days → stable) [6].

Near the upper boundary of the stability interval, small changes in neutron parity produce pronounced inertial and symmetry-driven effects.

This reflects an inertial disbalance consistent with predictions of the Alikhan model [5].

3.5. Neutron-Rich Region (A = 205 - 216)

Beyond A = 204, neutron surplus (N-Z = +9, …, +20) drives instability [6].

Half-lives decrease rapidly (minutes → nanoseconds).

These isotopes lie outside the stability interval, where excessive neutron density disrupts equatorial symmetry and force equilibrium, leading to strong instability [9] [10].

4. Discussion

These results suggest that spatial symmetry considerations can serve as a unifying framework linking empirical decay data with structural nuclear models.

A clear correlation between spatial symmetry, neutron parity, and experimental half-lives is established [6] [9] [10].

The Alikhan Symmetry Model complements the magic number concept (N = 82, 126) by interpreting magic closures as the completion of symmetric structural layers [1] [2] [5]. In particular, the neutron magic number N = 126 corresponds in the model to the completion of a fully symmetric neutron framework layer, after which additional neutrons necessarily occupy asymmetric positions, leading to instability.

Hg (Z = 80), being close to the magic proton number 82, exhibits quasi-magic behavior aligned with harmonic shell closure in the model [1] [8].

Stability is thus understood not only as quantum shell filling but also as a dynamic equilibrium between symmetry and force interactions [5] [9].

5. Conclusions

The Alikhan symmetry-based framework provides a coherent explanation for the stability of Mercury isotopes consistent with experimental observations [6].

By uniting structural symmetry, proton-neutron parity, and nuclear-Coulomb balance, the model refines the understanding of isotopic stability [5] [9].

Although qualitative, the approach uncovers systematic relationships that align with established nuclear principles, demonstrating that spatial symmetry considerations can enhance modern nuclear theories [1]-[4]. Future studies may extend this approach to other heavy nuclei to further evaluate its general applicability.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix

Table of Mercury (Hg) Isotopes

A	Neutron Framework	N	N-Z	Deficit/ Excess	Equatorial Balance	$T_{1/2}$
Hg	1 + 3 + 6 + 9 + 12 + 18 + 12 + 9 + 6 + 3 + 1 = 80 (Z = 80, Proton framework); fully symmetric, harmonic, ideally stable					
171	1 + 3 + 7 + 9 + 12 + 27 + 12 + 9 + 7 + 3 + 1 = 91	91	11	−25	1	80 µs
172	1 + 3 + 7 + 9 + 12 + 28 + 12 + 9 + 7 + 3 + 1 = 92	92	12	−24	0	420 µs
173	1 + 3 + 7 + 10 + 13 + 25 + 13 + 10 + 7 + 3 + 1 = 93	93	13	−23	1	1.1 ms
174	1 + 3 + 7 + 12 + 12 + 24 + 12 + 12 + 7 + 3 + 1 = 94	94	14	−22	0	2 ms
175	1 + 3 + 7 + 12 + 12 + 25 + 12 + 12 + 7 + 3 + 1 = 95	95	15	−21	1	10.8 ms
176	1 + 3 + 7 + 12 + 13 + 24 + 13 + 12 + 7 + 3 + 1 = 96	96	16	−20	0	20.4 ms
177	1 + 3 + 7 + 12 + 13 + 25 + 13 + 12 + 7 + 3 + 1 = 97	97	17	−19	1	127.3 ms
178	1 + 3 + 7 + 12 + 13 + 26 + 13 + 12 + 7 + 3 + 1 = 98	98	18	−18	0	269 ms
179	1 + 3 + 7 + 12 + 13 + 27 + 13 + 12 + 7 + 3 + 1 = 99	99	19	−17	1	1.09 s
180	1 + 3 + 7 + 12 + 13 + 28 + 13 + 12 + 7 + 3 + 1 = 100	100	20	−16	0	2.58 s
181	1 + 3 + 7 + 12 + 13 + 29 + 13 + 12 + 7 + 3 + 1 = 101	101	21	−15	1	3.6 s
182	1 + 3 + 7 + 12 + 13 + 30 + 13 + 12 + 7 + 3 + 1 = 102	102	22	−14	0	10.83 s
183	1 + 3 + 7 + 12 + 13 + 31 + 13 + 12 + 7 + 3 + 1 = 103	103	23	−13	1	9.4 s
184	1 + 3 + 7 + 12 + 12 + 34 + 12 + 12 + 7 + 3 + 1 = 104	104	24	−12	0	30.6 s
185	1 + 3 + 7 + 12 + 12 + 35 + 12 + 12 + 7 + 3 + 1 = 105	105	25	−11	1	49.1 s
186	1 + 3 + 7 + 12 + 12 + 36 + 12 + 12 + 7 + 3 + 1 = 106	106	26	−10	0	1.38 min
187	1 + 3 + 7 + 12 + 12 + 37 + 12 + 12 + 7 + 3 + 1 = 107	107	27	−9	1	1.9 min
188	1 + 3 + 7 + 12 + 16 + 30 + 16 + 12 + 7 + 3 + 1 = 108	108	28	−8	0	3.25 min
189	1 + 3 + 7 + 12 + 16 + 31 + 16 + 12 + 7 + 3 + 1 = 109	109	29	−7	1	7.6 min
190	1 + 3 + 7 + 12 + 17 + 30 + 17 + 12 + 7 + 3 + 1 = 110	110	30	−6	0	20 min
191	1 + 3 + 7 + 12 + 17 + 31 + 17 + 12 + 7 + 3 + 1 = 111	111	31	−5	1	49 min
192	1 + 3 + 7 + 12 + 18 + 30 + 18 + 12 + 7 + 3 + 1 = 112	112	32	−4	0	4.85 h
193	1 + 3 + 7 + 12 + 18 + 31 + 18 + 12 + 7 + 3 + 1 = 113	113	33	−3	1	3.8 h
194	1 + 3 + 7 + 12 + 19 + 30 + 19 + 12 + 7 + 3 + 1 = 114	114	34	−2	0	444 y
195	1 + 3 + 7 + 12 + 19 + 31 + 19 + 12 + 7 + 3 + 1 = 115	115	35	−1	1	10.53 h
196	1 + 3 + 7 + 12 + 18 + 34 + 18 + 12 + 7 + 3 + 1 = 116	116	36	0	0	Stable
197	1 + 3 + 7 + 12 + 18 + 35 + 18 + 12 + 7 + 3 + 1 = 117	117	37	1	1	64.14 h
198	1 + 3 + 7 + 12 + 18 + 36 + 18 + 12 + 7 + 3 + 1 = 118	118	38	2	0	Stable
199	1 + 3 + 7 + 12 + 18 + 37 + 18 + 12 + 7 + 3 + 1 = 119	119	39	3	1	Stable
200	1 + 3 + 7 + 12 + 19 + 36 + 19 + 12 + 7 + 3 + 1 = 120	120	40	4	0	Stable

Continued

201	1 + 3 + 7 + 12 + 19 + 37 + 19 + 12 + 7 + 3 + 1 = 121	121	41	5	1	Stable
202	1 + 6 + 6 + 12 + 18 + 36 + 18 + 12 + 6 + 6 + 1 = 122	122	42	6	0	Stable
203	1 + 6 + 6 + 12 + 18 + 37 + 18 + 12 + 6 + 6 + 1 = 123	123	43	7	1	46.595 d
204	1 + 7 + 6 + 12 + 18 + 36 + 18 + 12 + 6 + 7 + 1 = 124	124	44	8	0	Stable
205	1 + 7 + 6 + 12 + 18 + 37 + 18 + 12 + 6 + 7 + 1 = 125	125	45	9	1	5.14 min
206	1 + 7 + 7 + 12 + 18 + 36 + 18 + 12 + 7 + 7 + 1 = 126	126	46	10	0	8.15 min
207	1 + 7 + 7 + 12 + 19 + 37 + 19 + 12 + 7 + 7 + 1 = 127	127	47	11	1	2.9 min
208	1 + 7 + 7 + 12 + 19 + 36 + 19 + 12 + 7 + 7 + 1 = 128	128	48	12	0	42 min
209	1 + 7 + 7 + 12 + 19 + 36 + 19 + 12 + 7 + 7 + 1 = 129	129	49	13	1	37 s
210	1 + 4 + 6 + 12 + 18 + 48 + 18 + 12 + 6 + 4 + 1 = 130	130	50	14	0	10 min
211	1 + 4 + 6 + 12 + 18 + 49 + 18 + 12 + 6 + 4 + 1 = 131	131	51	15	1	>300 ns
212	1 + 4 + 7 + 12 + 18 + 48 + 18 + 12 + 7 + 4 + 1 = 132	132	52	16	0	>300 ns
213	1 + 4 + 7 + 12 + 18 + 49 + 18 + 12 + 7 + 4 + 1 = 133	133	53	17	1	>300 ns
214	1 + 4 + 7 + 12 + 19 + 48 + 19 + 12 + 7 + 4 + 1 = 134	134	54	18	0	>300 ns
215	1 + 4 + 7 + 12 + 19 + 49 + 19 + 12 + 7 + 4 + 1 = 135	135	55	19	1	>300 ns
216	1 + 4 + 7 + 10 + 19 + 54 + 19 + 10 + 7 + 4 + 1 = 136	136	56	20	0	>300 ns

Analysis

Isotopes **Hg-171 to Hg-193** are radioactive, with half-lives ranging from **80 µs to 3.8 hours**.

In this region, the presence of an **odd neutron in the equatorial layer** creates a small imbalance (1n), leading to a moderate decrease in stability. The **neutron deficit (from −25 to −3)** dominates, resulting in a gradual increase of half-life with rising neutron number.

The transition from **Hg-193 to Hg-194** represents a sharp leap: from **3.8 hours to 444 years**, because **Hg-194** lies near the **lower boundary of the stability interval**, and its **equatorial balance equals zero**.

From **Hg-194 to Hg-195**, the half-life drops dramatically from **444 years to 10.53 hours** due to the reappearance of an **odd neutron (1n)** in the equatorial layer, creating a disbalance.

From **Hg-195 to Hg-196**, the half-life jumps from **10.53 hours to complete stability**, since the equatorial layer now contains an **even number of neutrons**, restoring balance and priority stability.

In the interval **Hg-198 to Hg-202**, **Coulomb and nuclear forces** reach an equilibrium limit. Even though **Hg-199** and **Hg-201** have odd neutrons, they remain stable because they lie within this equilibrium zone.

Transitions **Hg-202 → Hg-203** and **Hg-203 → Hg-204** are also accompanied by abrupt changes. Near the **upper boundary of the stability interval**, the **neutron excess** and **inertial imbalance** (odd 203 vs. even 204) become pronounced.

In the region **Hg-205 to Hg-210**, the half-life is in the **minute range**, where **neutron excess** predominates.

From **Hg-211 to Hg-216**, increasing neutron excess leads to **very short half-lives (~300 ns)**, indicating strong instability in this neutron-rich domain.