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Critical Examination of Gamow's Theory of Alpha Particle Decay

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ABSTRACT

Gamow's Theory of Alpha Particle Decay was initially formulated for a limited set of nuclei. In this study, the researchers extend the scope and assessed the applicability of the theory to a broader range of nuclides especially those with different proton and neutron compositions. Three objectives were formulated to undertake the research. The researcher utilized one-dimensional WKB approximation to calculate the probability of tunneling through the potential barrier, which is a simplification compared to other formulas. The Geiger-Nuttall law, which describes a dependence of the disintegration constant on the range of α-particles, was deduced using the Gamow theory describing the passage of the α-particles through the Coulomb barrier by the quantum mechanical tunneling effect. Ground-to-ground state α-transitions for α-active nuclides were analyzed based on their half-lives and their dependence on various factors. The study revealed that all α-active nuclides whose Z ranges between 70 to100 undergoes similar alpha decay processes.

Keywords:
Alpha decay,
WKB Approximation,
Gamow Theory,
Geiger-Nuttall law.

INTRODUCTION

The exploration of alpha particle decay is fundamental to nuclear physics, offering crucial insights into the dynamics of atomic nuclei and the underlying forces governing their stability. George Gamow's groundbreaking theory, developed in the early 20th century, introduced the concept of quantum tunneling to elucidate how alpha particles overcome the strong nuclear force that confines them within the nucleus (Gamow, 1928). This research critically examines Gamow's Theory of Alpha Particle Decay, aiming to evaluate its applicability in diverse nuclear scenarios and explore potential refinements or extensions to enhance its accuracy.

The objectives of this study are threefold: to assess the suitability of Gamow's Theory across a broader range of nuclides and nuclear configurations, to scrutinize the assumptions and simplifications inherent in the theory, and to conduct an in-depth analysis of the quantum mechanical aspects of alpha decay. The focus is primarily on the theoretical aspects of Gamow's Theory, encompassing nuclear physics, quantum mechanics, and mathematical modeling. Discussions of experimental results may be included for comparative purposes.

The critical examination of Gamow's Theory of Alpha Particle Decay holds significant scientific importance, contributing to our understanding of nuclear physics, quantum mechanics, and the behavior of atomic nuclei. This investigation is poised to shed light on the intricacies of alpha particle decay, impacting various scientific domains, including nuclear energy, particle physics, and astrophysics.

Furthermore, this research delves into the theoretical underpinnings guiding the critical examination, incorporating foundational concepts such as quantum tunneling, Maxwell-Boltzmann-Gibbs statistics, the Geiger-Nuttall law, the Goldberger-Watson decay theory, and the Unified Fission Model based on a Modified Wood-Saxon potential (Bohr, 1948; Gamow, 1928; Goldberger & Watson, 1969). These frameworks significantly contribute to our comprehension of nuclear physics and quantum mechanics, with potential practical implications in diverse scientific fields.

The study also addresses challenges in quantum mechanics, where exact solutions to the Schrödinger equation proved elusive. Various methods, including perturbation theory, the variational method, and the Wentzel-Kramers-Brillouin (WKB) approximation, have been employed. Semi-classical approximations, exemplified by the WKB method, prove useful in molecular dynamics, offering computational ease in studying nuclear motion (Wentzel, 1926; Kramers, 1926; Brillouin, 1926). However, these approximations have limitations in accurately tracking electron movement or characterizing macroscopic systems. The WKB approximation stands out for its effectiveness in calculating tunneling rates through potential barriers and determining bound state energies in one-dimensional problems, reflecting a method named after its proponents Wentzel, Kramers, and Brillouin.

Theoretical frame work

The WKB (Wentzel-Kramers-Brillouin) approximation is a method used to find approximate solutions to the Schrödinger equation for a quantum system. The derivation begins with the time-independent Schrödinger Equation:

$$\left[-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}+U(x)\right]\psi = E\psi \qquad (1)$$

Rearranging it, we get:

$$-\hbar^2\psi'' = 2m(E-U)\psi$$

Now, defining

$$p(x) = \frac{\sqrt{2m(E-U)}}{\hbar}$$

We can rewrite the equation as:

$$\psi'' = -p(x)^2\psi$$

Motivated by the free particle solution, we assume

$$\psi = \frac{c}{\sqrt{p(x)}}e^{iS(x)/\hbar}$$

Where S(x) is a real function. By substituting this into the Schrödinger equation and expanding in powers of $\hbar$, we obtain a series of equations. The WKB approximation for the wave function ψ is then derived as:

$$\psi = \frac{c}{\sqrt{p(x)}}e^{\left(\frac{i}{\hbar}\right)\int_0^x p(x)dx} \qquad (2)$$

The WKB method is applied to the tunneling effect of an alpha particle through a one-dimensional rectangular potential barrier. The transmission probability is derived as:

$$T = e^{-\frac{2kL}{\hbar}}$$

Where k is related to the potential energy in the barrier region. Gamow's theory stands as a cornerstone in explaining alpha particle decay, with the transmission probability (T) playing a pivotal role, intricately linked to the decay constant. This decay constant is crucial in calculating alpha decay half-lives, and empirical formulas such as the Improved Gamow-like (IMGL) and the Modified Gamow-like model (MGLM) have been introduced to refine predictions, taking into account the quantum tunneling of alpha particles through the nuclear potential barrier.

Gamow's theory extends its versatility across diverse nuclides, offering a framework to analyze alpha decay half-lives and their dependencies on various factors. Derived from Gamow's theory, the Geiger-Nuttall law establishes a correlation between the disintegration constant and the range of alpha particles, providing valuable insights into the probability of alpha decay for different nuclides (Munkhsaikhan et al, 2020).

In the realm of alpha decay, the mean lifetime (τ) of a nucleus is intricately tied to the transmission probability formula, expressed in terms of physical constants and parameters. The alpha decay half-life from the Modified Gamow-like model (MGLM) is characterized by a formula involving the decay hindrance factor (h), accounting for odd-neutrons or odd-protons. This factor varies for different nuclei, being zero for even-even nuclei and doubling for odd-odd nuclei (Zdeb et al, 2014).

The decay constant (λ) crucially determines alpha decay rates and is influenced by parameters such as charge radius, assault frequency, angular momentum, and isospin effect (Zdeb et al, 2014). Empirical formulas, specifically IMGL and MGLM, have demonstrated enhanced predictive accuracy compared to alternative models (Azeez et al, 2022).

A semi classical approach, the Wentzel-Kramers-Brillouin (WKB) approximation, provides an asymptotic solution to the Schrödinger equation for a potential barrier. In this context, the WKB method is applied to analyze the tunneling effect of alpha particles through a one-dimensional rectangular potential barrier.

However, despite its successes, Gamow's theory relies on certain assumptions and simplifications. These include its description using introductory quantum theory, a one-dimensional WKB approximation for tunneling probabilities, and predictions for super-heavy nuclei based on a phenomenological model (Trisan, 2012). Modified versions of the Gamow-like model and empirical formulas have been introduced to enhance prediction accuracy (Roger, 1986).

Quantum effects play a pivotal role in alpha particle decay, involving the dissociation of two protons and two neutrons. Simplified quantum models within introductory quantum theory have proven successful in capturing this complex process (Serot et al, 1994). Predictions are influenced by factors such as the energy of the initial quasi-stationary state and preparation methods (Sergei et al, 2008). The Schrödinger Equation and the WKB approximation emerge as fundamental tools in exploring the tunneling effect, with a one-dimensional rectangular potential barrier, divided into three regions, forming the basis for understanding barrier penetration (Arati et al, 2012). This nuanced exploration contributes significantly to our comprehension of alpha particle decay in both theoretical and practical contexts within nuclear physics.

The probability for tunneling effect or barrier penetration can be obtained by considering a one dimensional rectangular potential barrier of the form:

$$v_{(x)} = \begin{cases} v_0 & 0 < x < L \\ 0 & x < 0,\ x > L \end{cases}$$

An alpha particle of total energy E in the region x<0 is incident upon barrier. The barrier is broken up into three regions:

Region I: 0 < x, V(x) = 0

Schrödinger's equation:

$$\frac{d^2\psi_{1(x)}}{dx^2}+\frac{2m}{ħ^2}E\psi_{1(x)}=0$$

General solution:

$$\psi_{1(x)}=Ae^{ik_1x}+Be^{-ik_1x} \quad (3)$$

Region II: $0 < x < L$, $V(x) = V_0$

Schrödinger's equation:

$$\frac{d^2\psi_{2(x)}}{dx^2}+\frac{2m}{ħ^2}(E-V_0)\psi_{2(x)}=0$$

General solution:

$$\psi_{2(x)}=Ce^{k_2x}+De^{-k_2x} \quad (4)$$

Region III: $x > L$, $V(x) = 0$

Schrödinger's equation:

$$\frac{d^2\psi_{3(x)}}{dx^2}+\frac{2m}{ħ^2}E\psi_{3(x)}=0$$

General solution:

$$\psi_{3(x)}=Fe^{ik_1x} \quad (5)$$

The constants A, B, C, D, and F are determined by applying boundary conditions at $x=0$ and $x=L$.

$$\psi_{1(0)}=\psi_{2(0)}$$

and

$$\psi^I_{1(0)}=\psi^I_{2(0)}$$

This implies that,

$$A+B=C+D \quad (6)$$

$$ik_1A-ik_1B=k_2C-k_2 \quad (7)$$

Multiplying equation (6) by ik_1 and equation (7) by 1 and adding them:

$$ik_1A+ik_1B=ik_1C+ik_1D$$

$$ik_1A-ik_1B=k_2C-k_2D$$

This implies that,

$$2ik_1A=C(ik_1+k_2)+D(ik_1-k_2)$$

$$A=\frac{C}{2}\left(\frac{ik_1}{ik_1}+\frac{k_2}{ik_1}\right)+\frac{D}{2}\left(\frac{ik_1}{ik_1}-\frac{k_2}{ik_1}\right)$$

Therefore,

$$A=\frac{C}{2}\left(1+\frac{k_2}{ik_1}\right)+\frac{D}{2}\left(1-\frac{k_2}{ik_1}\right) \quad (8)$$

At $x = L$

$$\psi_{2(l)}=\psi_{3(l)}$$

and

$$\psi^I_{2(l)}=\psi^I_{3(l)}$$

This implies that,

$$Ce^{k_2l}+De^{-k_2l}=Fe^{ik_1l} \quad (9)$$

$$k_2Ce^{k_2l}-k_2De^{-k_2l}=ik_1Fe^{ik_1l} \quad (10)$$

By multiplying equation (9) by k_2 and equation (10) by 1 and adding them:

$$k_2Ce^{k_2l}+k_2De^{-k_2l}=k_2Fe^{ik_1l}$$

$$k_2Ce^{k_2l}-k_2De^{-k_2l}=ik_1Fe^{ik_1l}$$

This implies that,

$$2k_2Ce^{k_2l}=(k_2+ik_1)Fe^{ik_1l}$$

Therefore,

$$C=\left(1+\frac{ik_1}{k_2}\right)\frac{Fe^{(ik_1-k_2)l}}{2} \quad (11)$$

Also, by multiplying equation (9) by k_2 and equation (10) by 1 and subtracting them:

$$k_2Ce^{k_2l}+k_2De^{-k_2l}=k_2Fe^{ik_1l}$$

$$k_2Ce^{k_2l}-k_2De^{-k_2l}=ik_1Fe^{ik_1l}$$

This implies that,

$$2k_2De^{-k_2l}=(k_2-ik_1)Fe^{ik_1l}$$

$$D=\left(\frac{k_2}{k_2}-\frac{ik_1}{k_2}\right)\frac{Fe^{ik_1l}.e^{k_2l}}{2}$$

Therefore,

$$D=\left(1-\frac{ik_1}{k_2}\right)\frac{Fe^{(ik_1+k_2)l}}{2} \quad (12)$$

Substituting equations (11) and (12) into equation (8) we get,

$$A=\left(1+\frac{k_2}{ik_1}\right)\left(1+\frac{ik_1}{k_2}\right)\frac{Fe^{(ik_1-k_2)l}}{4}+\left(1-\frac{k_2}{ik_1}\right)\left(1-\frac{ik_1}{k_2}\right)\frac{Fe^{(ik_1+k_2)l}}{4} \quad (13)$$

Since in practice as the barrier high L is wide $k_2L \geq 1$, then the first term of equation 13 can be neglected in comparing with the second term. This implies that,

$$A=\left(1-\frac{k_2}{ik_1}\right)\left(1-\frac{ik_1}{k_2}\right)\frac{Fe^{(ik_1+k_2)l}}{4} \quad (14)$$

But

$$\left|\frac{A}{F}\right|^2=\left|\frac{A}{F}\right|\left|\frac{A}{F}\right|^*=\frac{\left(k_1^2+k_2^2\right)^2}{16k_1^2k_2^2}e^{2k_2l}$$

But

$$k_1^2=\frac{2m}{ħ^2}E$$

and

$$k_2^2=\frac{2m}{ħ^2}(E-V_0)$$

But transmission probability T is given as

$$T=\left|\frac{F}{A}\right|^2=\frac{16k_1^2k_2^2}{\left(k_1^2+k_2^2\right)^2}e^{-2k_2l} \quad (15)$$

By substituting the values of k_1^2 and k_2^2 into equation (15). Then, the factor before the exponential part is usually of the order of magnitude unity (the maximum value is for when $K_1 = K_2$). This implies that,

$$\frac{16k_1^2k_2^2}{\left(k_1^2+k_2^2\right)^2}\approx 1$$

Or

$$T=e^{-2k_2l} \quad (16)$$

Equation (16) gives us the probability that an alpha particle with a total energy less than the barrier high $E < V_0$ will penetrate the barrier of the width L. If the potential is not constant in the region $0 < x < L$ it can be approximated with a series of small steps, each with a constant potential.

Now let us consider a radioactive nucleus which undergoes a decay in which an alpha particle is emitted as shown in the equation below

$${}^A_ZX \rightarrow Y^{A-4}_{Z-2}+{}^4_2H \quad (17)$$

The transmission probability (T) for the alpha particle to penetrate the barrier is given by

$$T=e^{-\frac{2G}{ħ}} \quad (18)$$

where k2 is related to the potential difference V0 and the energy E. The transmission probability (T) is a pivotal outcome in the analysis of an alpha particle's interaction with a potential barrier. It quantifies the likelihood of an alpha particle, possessing total energy E less than the barrier height V0, tunneling through a potential barrier of width L. Equation (16) crystallizes into the final expression for T, offering a numeric representation of the alpha particle's probability of tunneling through the potential barrier.

This probability becomes particularly crucial when the potential is not uniform within the region 0 < x < L. In such cases, the WKB approximation comes to the forefront, offering a method to approximate the potential with a series of small steps, each characterized by a constant potential.

The WKB approximation specifically comes into play when deriving the transmission probability for an alpha particle encountering a rectangular potential barrier. The exponential term within the result holds the essence of the tunneling effect. The derivation process involves applying boundary conditions and solving for coefficients in distinct regions. The final expression, as encapsulated in Equation (18), hinges on the particle's energy and the characteristics of the potential barrier.

In the context of alpha particle decay, Equation (18) unveils the transmission probability (T) for an alpha particle navigating through a Coulomb barrier. This calculation takes into account the tunneling phenomenon, wherein the alpha particle faces a Coulomb barrier created by the electrostatic potential energy between the nucleus and the alpha particle.

The nucleus, in this scenario, is characterized by an initial charge of +Ze, while the alpha particle being emitted carries a charge of +2e. This juxtaposition of charges sets the stage for the intricate interplay that influences the probability of tunneling through the electrostatic potential barrier. The mathematical expression in Equation (18) serves as a quantitative representation of this intricate interplay, shedding light on the probabilities inherent in the alpha particle decay process. The electrostatic potential energy barrier between the nucleus and the alpha particle is given by Coulomb's law as:

$$V_{(r)} = \frac{2(Z-2)ke^2}{r} \quad \text{for } r \geq r_0 \tag{19}$$

where e is the electron's charge, Z is the atomic number, and r0 is the distance inside the nucleus. The total energy (E) of the alpha particle is given by

$$E = \frac{2(Z-2)ke^2}{r_1} \tag{20}$$

where r1 is the distance at which the potential energy is equal to the total energy. The integral G is further simplified as

$$G = \int_{r_0}^{r_1} 2m\left(\frac{2(Z-2)e^2}{r} - \frac{2(Z-2)e^2}{r_1}\right)^{1/2} dr$$

$$= \left[\frac{2(Z-2)e^2}{v}\right](2\theta - 2\sin\theta\cos\theta) \tag{21}$$

This analysis delves into the quantum mechanical intricacies underlying the tunneling process within the context of alpha decay. Central to this exploration is the Coulomb barrier, shaped by the electrostatic potential energy existing between the nucleus and the emitted alpha particle. At the heart of this investigation is the transmission probability (T), a metric that numerically captures the likelihood of the alpha particle successfully tunneling through the electrostatic barrier.

Equation (18) stands as a crucial juncture in this quantum journey, wherein the transmission probability is distilled into a form where the term 'G' is expressed in relation to an integral involving potential energy and mass. This equation serves as a powerful tool for determining the probability of alpha particle tunneling, offering a nuanced understanding of the dynamics inherent in alpha decay.

The decay process itself involves the emission of an alpha particle from a radioactive nucleus denoted as ZAX. This emission results in the formation of a new nucleus (Z−2A−4Y) and a released alpha particle (24H). The integral 'G' encapsulates a square root of a potential energy term, while the exponential term carries the weight of the probability associated with the alpha particle successfully tunneling through the electrostatic barrier. This analytical approach, particularly when Equation (21) is substituted into Equation (18), provides a comprehensive framework for unraveling the quantum mechanical aspects of nuclear decay processes.

Such analyses, deeply rooted in quantum mechanics, offer a profound understanding of the intricacies involved in the alpha decay phenomenon. By quantifying the probability of tunneling, researchers gain valuable insights into the fundamental nature of nuclear decay, contributing to the broader comprehension of quantum phenomena in the microscopic realm.

$$T = \exp\left[\left(\frac{-4(Z-2)e^2}{\hbar v}\right)(2\theta - 2\sin\theta\cos\theta)\right] \tag{22}$$

Equation (22) gives one form of expression for transmission probability.

$$T = \exp\left[\left(\frac{-8(Z-2)e^2}{\hbar v}\right)(\theta - \sin\theta\cos\theta)\right] \tag{23}$$

$$\cos\theta = \left(\frac{r_0}{r_1}\right)^{1/2} \tag{24a}$$

$$\theta = \cos^{-1}\left(\frac{r_0}{r_1}\right)^{1/2} \tag{24b}$$

$$\sin\theta = (1 - \cos^2\theta)^{1/2} \tag{24c}$$

Substituting equations (24a), (24b) and (24c) into equation 23 we get,

$$T = \exp\left[\left(\frac{-8(Z-2)e^2}{\hbar v}\right)\left(\cos^{-1}\left(\frac{r_0}{r_1}\right)^{1/2} - \left(1 - \frac{r_0}{r_1}\right)^{1/2}\left(\frac{r_0}{r_1}\right)^{1/2}\right)\right] \tag{25}$$

$$y = \left(\frac{r_0}{r_1}\right)^{1/2} \tag{26}$$

By substituting equation (26) into equation (25) we get,

$$T = \exp\left[\frac{-8\pi^2(Z-2)e^2}{hv} + \frac{16\pi e}{h}\{mr_0(z-2)\}^{1/2}\right] \tag{27}$$

It is assumed that an alpha particle moves back and forth more or less freely inside the nucleus with speed v. If r_0 is the radius of the nucleus, the number of times it hits the nucleus boundary per second.

$$n = \frac{v}{2r_0} \quad (28)$$

Since distance traversed by alpha particle for one collision is $2r_0$. From de – Broglie hypothesis

$$\lambda = \frac{h}{mv} \quad (29)$$

By substituting v in equation (29) into equation (28) we get,

$$n = \frac{h}{2mr_0\,\lambda} \quad (30)$$

From the uncertainty principle

$$\Delta x \Delta p \approx \hbar$$

$$\Delta x \approx \frac{\hbar}{\Delta p} \approx \lambda \approx 2r_0$$

$$n = \frac{h}{2mr_0}$$

$$2r_0 = \frac{h}{4mr_0^2}$$

Each time $\alpha -$ particle strikes the barrier (nucleus boundary), the probability of penetration of $\alpha -$ particle per second is:

$$P = nT \quad (31)$$

By substituting equations (27) and (30) into equation (31) we get,

$$P = \frac{h}{4mr_0^2}\exp\left[\frac{-8\pi^2(Z-2)e^2}{hv} + \frac{16\pi e}{h}\{mr_0(z-2)\}^{1/2}\right] \quad (32)$$

$$\ln P = In\frac{h}{4mr_0^2} - \frac{8\pi^2(Z-2)e^2}{hv} + \frac{16\pi e}{h}\{mr_0(z-2)\}^{1/2} \quad (33)$$

Equation (33) is known as Geiger Nuttel law. The mean life time of nucleus is given as:

$$\tau = \frac{1}{p} \quad (34)$$

By substituting equation (31) into equation (34) we get,

$$\tau = \frac{1}{nT} \quad (35)$$

By substituting equation (33) into equation (35) we get,

$$\tau = \frac{4mr_0^2}{h}\exp\left[\frac{8\pi^2(Z-2)e^2}{hv} + \frac{16\pi e}{h}\{mr_0(z-2)\}^{1/2}\right] \quad (36)$$

where $r_0 = 2 \times 10^{-15}\, Z^{1/2}$ m. The life time calculated from this formula is in close agreement with experimental value.

RESULTS AND DISCUSSION

Results

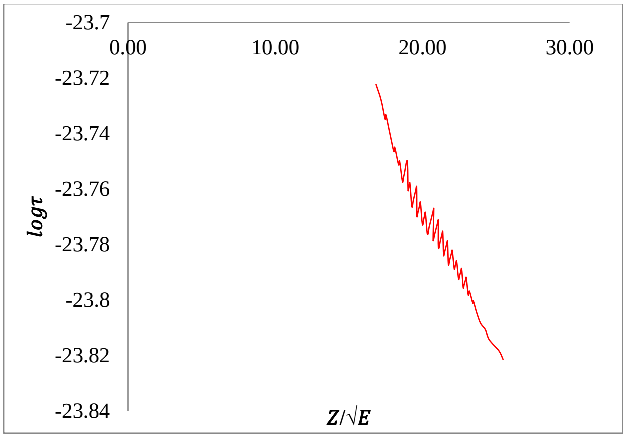

Figure 1: Graph of $log\tau\ against\ Z/\sqrt{E}$

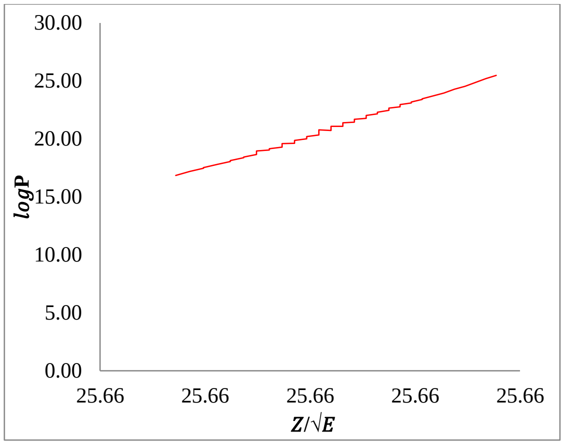

Figure 2: Graph of $logP\ against\ Z/\sqrt{E}$

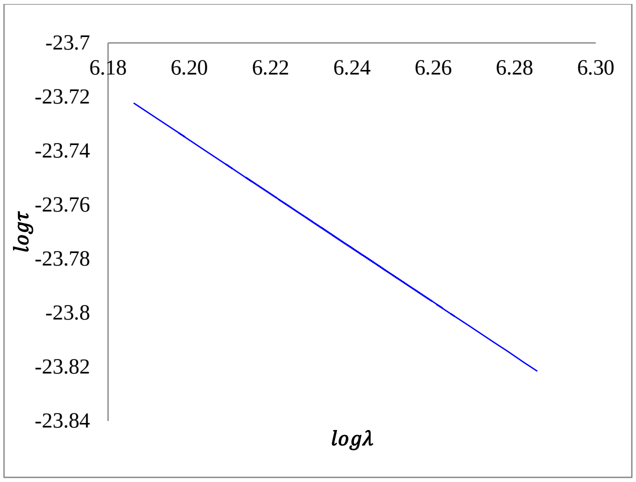

Figure 3: Graph of $log\tau\ against\ log\lambda$

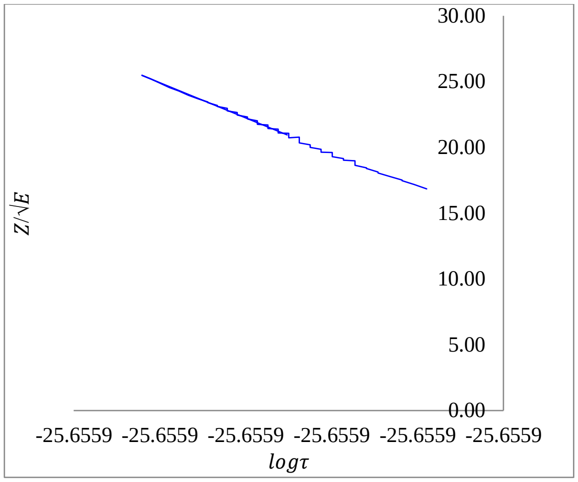

Figure 4: Graph of $log\tau\ against\ Z/\sqrt{E}$

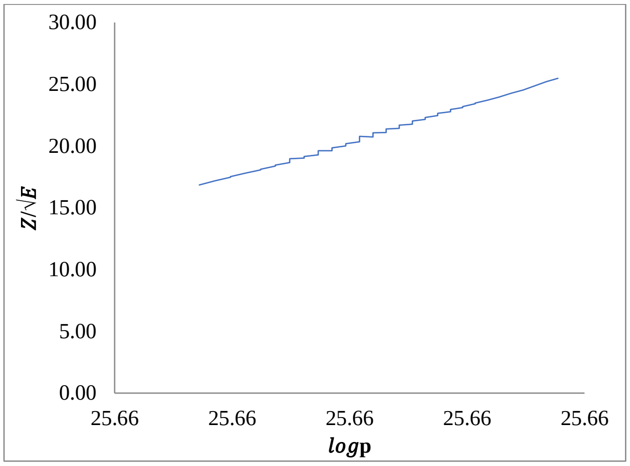

Figure 5: Graph of $logP\ against\ Z/\sqrt{E}$

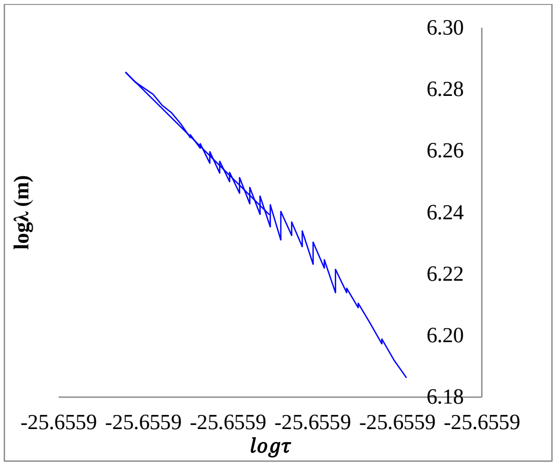

Figure 6: Graph of $log\tau\ against\ log\lambda$

Figure 1 and Figure 2 show a relationship between logτ and Z/√E, suggesting an inverse relationship between the alpha particle's half-life logarithm and its energy. This suggests a systematic interplay between the alpha particle's energy and its decay time. Expanding the scope to the 70-94 range, a distinct trend emerges, with elements within this range exhibiting longer half-lives compared to their counterparts outside this range.

Figure 3 reveals a connection between logτ and logλ, revealing a connection between half-life and alpha particle wavelength. As logτ increases, logλ decreases, indicating shorter half-lives are associated with longer wavelengths.

Figure 2 shows a different trend, with an increase in logp corresponding to an increase in Z/√E, suggesting that radioactive elements with Z ranging from 70-94 have a lower probability of penetrating the potential barrier compared to other radioactive elements.

Figure 4 revisits the inverse proportionality between logτ and Z/√E, indicating an increased energy requirement for alpha particle decay. This adds complexity to the understanding of alpha particle decay dynamics.

Figure 5 substantiates the trends observed in Figure 2, showing similar and longer wavelengths for elements with Z = 94 downwards, while elements with Z = 70 to 94 display shorter wavelengths.

Discussion

The study provides a comprehensive analysis of alpha particle decay dynamics, revealing intricate relationships and distinct trends. The inverse proportionality between logτ and Z/√E indicates that as the logarithm of the alpha particle's half-life decreases, the energy of the particle increases. This relationship is consistent across various nuclides, emphasizing a fundamental interplay between alpha particle energy and decay time. Expanding the investigation to radioactive elements within the Z range of 70-94 emphasizes the significance of this relationship, indicating longer half-lives for elements within this specific Z range.

The correlation between logp and Z/√E suggests that elements with Z ranging from 70-94 possess a lower probability of penetrating the potential barrier, pointing to the momentum of the alpha particle as a key factor influencing penetration probability. The exploration of the relationship between logτ and logλ reveals a fascinating connection between the half-life and the wavelength of alpha particles, implying shorter half-lives are associated with longer wavelengths.
The study also highlights an increased energy requirement for alpha particle decay for radioactive elements within the Z range of 74-100, suggesting a higher energy threshold for the decay process in this specific Z range. The trends observed in Figure 5 further substantiate the penetration probability insights from Figure 2, indicating nearly equal probabilities for elements with Z ranging from 74-100.
Finally, Figure 6 delves into the wavelength characteristics of alpha particles, revealing a distinct pattern: elements with Z = 94 downward exhibit similar and longer wavelengths, while elements with Z = 70 to 94 display shorter wavelengths.

CONCLUSION

In conclusion, the study provides valuable insights into the intricacies of alpha particle decay dynamics, making substantial contributions to the broader body of knowledge in nuclear physics.

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Table 1: The table below shows different alpha transition of radioactive elements with frequency varying (n)

α *transition*	$L(fm)$	$Tsch$	$V(m/s)$	$\lambda\,(m)$	$n(s^{-1})$	$LogP$	$t(s)$	$logt$	$log\lambda\,(m)$	$Z/\sqrt{E}$
^{146}Sm→ ^{142}Nd	10.43	0.40	2.11E+09	1.54E+06	5.3E+23	23.72	1.90E-24	-23.7223	6.19	16.85
^{150}Gd→ ^{146}Sm	10.53	0.39	2.14E+09	1.56E+06	5.3E+23	23.73	1.87E-24	-23.7279	6.19	17.19
^{150}Dy→ ^{146}Gd	10.53	0.38	2.17E+09	1.58E+06	5.4E+23	23.73	1.84E-24	-23.7348	6.20	17.46
^{154}Dy→ ^{150}Gd	10.63	0.38	2.16E+09	1.58E+06	5.4E+23	23.73	1.85E-24	-23.7333	6.20	17.52
^{154}Er→ ^{150}Dy	10.63	0.37	2.20E+09	1.60E+06	5.5E+23	23.74	1.82E-24	-23.74	6.20	17.80
^{154}Yb→ ^{150}Er	10.63	0.37	2.23E+09	1.62E+06	5.6E+23	23.75	1.79E-24	-23.7465	6.21	18.06
^{158}Yb→ ^{154}Er	10.72	0.36	2.22E+09	1.62E+06	5.6E+23	23.75	1.80E-24	-23.745	6.21	18.12
^{158}Hf→^{154}Yb	10.72	0.36	2.26E+09	1.64E+06	5.6E+23	23.75	1.77E-24	-23.7513	6.22	18.39
^{162}Hf→^{158}Yb	10.81	0.36	2.25E+09	1.64E+06	5.6E+23	23.75	1.78E-24	-23.7499	6.21	18.45
^{158}W→^{154}Hf	10.72	0.35	2.29E+09	1.67E+06	5.7E+23	23.76	1.75E-24	-23.7574	6.22	18.65
^{162}W→^{158}Hf	10.81	0.35	2.28E+09	1.66E+06	5.7E+23	23.76	1.75E-24	-23.756	6.22	18.71
^{166}W→^{162}Hf	10.90	0.35	2.27E+09	1.65E+06	5.7E+23	23.75	1.76E-24	-23.7546	6.22	18.77
^{180}W→^{176}Hf	11.21	0.34	2.25E+09	1.64E+06	5.6E+23	23.75	1.78E-24	-23.7499	6.21	18.97
^{166}Os→^{162}W	10.90	0.34	2.30E+09	1.68E+06	5.8E+23	23.76	1.74E-24	-23.7605	6.22	19.03
^{170}Os→^{166}W	10.99	0.34	2.30E+09	1.67E+06	5.7E+23	23.76	1.74E-24	-23.7592	6.22	19.09
^{174}Os→^{170}W	11.08	0.34	2.29E+09	1.67E+06	5.7E+23	23.76	1.75E-24	-23.7578	6.22	19.15
^{166}Pt→^{162}Os	10.90	0.34	2.34E+09	1.70E+06	5.8E+23	23.77	1.71E-24	-23.7663	6.23	19.29
^{172}Pt→^{168}Os	11.04	0.33	2.32E+09	1.69E+06	5.8E+23	23.76	1.72E-24	-23.7643	6.23	19.38
^{176}Pt→^{172}Os	11.12	0.33	2.32E+09	1.69E+06	5.8E+23	23.76	1.73E-24	-23.763	6.23	19.44
^{180}Pt→^{176}Os	11.21	0.33	2.31E+09	1.68E+06	5.8E+23	23.76	1.73E-24	-23.7617	6.23	19.49
^{184}Pt→^{180}Os	11.29	0.32	2.30E+09	1.68E+06	5.8E+23	23.76	1.74E-24	-23.7604	6.22	19.55
^{188}Pt → ^{184}Os	11.38	0.32	2.30E+09	1.67E+06	5.7E+23	23.76	1.74E-24	-23.7592	6.22	19.61
^{172}Hg → ^{168}Pt	11.04	0.33	2.35E+09	1.71E+06	5.9E+23	23.77	1.70E-24	-23.7699	6.23	19.63
^{176}Hg → ^{172}Pt	11.12	0.32	2.35E+09	1.71E+06	5.9E+23	23.77	1.70E-24	-23.7686	6.23	19.69
^{180}Hg → ^{176}Pt	11.21	0.32	2.34E+09	1.70E+06	5.9E+23	23.77	1.71E-24	-23.7673	6.23	19.75
^{184}Hg → ^{180}Pt	11.29	0.32	2.33E+09	1.70E+06	5.8E+23	23.77	1.71E-24	-23.766	6.23	19.81
^{188}Hg → ^{184}Pt	11.38	0.32	2.33E+09	1.69E+06	5.8E+23	23.76	1.72E-24	-23.7648	6.23	19.86
^{180}Pb → ^{176}Hg	11.21	0.32	2.37E+09	1.73E+06	5.9E+23	23.77	1.69E-24	-23.7728	6.24	20.00
^{186}Pb → ^{182}Hg	11.33	0.31	2.36E+09	1.72E+06	5.9E+23	23.77	1.69E-24	-23.7709	6.23	20.09
^{190}Pb → ^{186}Hg	11.42	0.31	2.35E+09	1.71E+06	5.9E+23	23.77	1.70E-24	-23.7697	6.23	20.15
^{194}Pb → ^{190}Hg	11.50	0.31	2.35E+09	1.71E+06	5.9E+23	23.77	1.70E-24	-23.7685	6.23	20.20
^{186}Po → ^{182}Hg	11.33	0.31	2.39E+09	1.74E+06	6.0E+23	23.78	1.67E-24	-23.7763	6.24	20.34
^{194}Po → ^{190}Hg	11.50	0.30	2.38E+09	1.73E+06	5.9E+23	23.77	1.68E-24	-23.7738	6.24	20.45
^{198}Po → ^{194}Hg	11.58	0.30	2.37E+09	1.72E+06	5.9E+23	23.77	1.69E-24	-23.7727	6.24	20.51
^{202}Po → ^{198}Hg	11.66	0.30	2.36E+09	1.72E+06	5.9E+23	23.77	1.69E-24	-23.7715	6.24	20.56
^{206}Po → ^{202}Hg	11.73	0.29	2.36E+09	1.72E+06	5.9E+23	23.77	1.70E-24	-23.7704	6.23	20.62
^{210}Po → ^{206}Hg	11.81	0.29	2.35E+09	1.71E+06	5.9E+23	23.77	1.70E-24	-23.7692	6.23	20.67
^{214}Po → ^{210}Hg	11.89	0.29	2.35E+09	1.71E+06	5.9E+23	23.77	1.71E-24	-23.7681	6.23	20.72
^{218}Po → ^{214}Hg	11.96	0.29	2.34E+09	1.70E+06	5.8E+23	23.77	1.71E-24	-23.7671	6.23	20.77
^{196}Rn → ^{192}Po	11.54	0.30	2.40E+09	1.75E+06	6.0E+23	23.78	1.67E-24	-23.7785	6.24	20.73
^{202}Rn → ^{198}Po	11.66	0.29	2.39E+09	1.74E+06	6.0E+23	23.78	1.67E-24	-23.7767	6.24	20.81
^{206}Rn → ^{202}Po	11.73	0.29	2.39E+09	1.74E+06	6.0E+23	23.78	1.68E-24	-23.7756	6.24	20.87
^{210}Rn → ^{206}Po	11.81	0.29	2.38E+09	1.73E+06	5.9E+23	23.77	1.68E-24	-23.7745	6.24	20.92
^{214}Rn → ^{210}Po	11.89	0.29	2.37E+09	1.73E+06	5.9E+23	23.77	1.69E-24	-23.7734	6.24	20.97
^{218}Rn → ^{214}Po	11.96	0.28	2.37E+09	1.72E+06	5.9E+23	23.77	1.69E-24	-23.7723	6.24	21.03
^{222}Rn → ^{218}Po	12.04	0.28	2.36E+09	1.72E+06	5.9E+23	23.77	1.69E-24	-23.7712	6.24	21.08
^{204}Ra → ^{200}Rn	11.70	0.29	2.42E+09	1.76E+06	6.0E+23	23.78	1.65E-24	-23.7813	6.25	21.09
^{214}Ra → ^{210}Rn	11.89	0.28	2.40E+09	1.75E+06	6.0E+23	23.78	1.67E-24	-23.7785	6.24	21.22

^{218}Ra → ^{214}Rn	11.96	0.28	2.40E+09	1.74E+06	6.0E+23	23.78	1.67E-24	-23.7774	6.24	21.27
^{222}Ra → ^{218}Rn	12.04	0.28	2.39E+09	1.74E+06	6.0E+23	23.78	1.67E-24	-23.7763	6.24	21.33
^{226}Ra → ^{222}Rn	12.11	0.27	2.38E+09	1.74E+06	6.0E+23	23.78	1.68E-24	-23.7753	6.24	21.38
^{212}Th → ^{208}Ra	11.85	0.28	2.43E+09	1.77E+06	6.1E+23	23.78	1.64E-24	-23.784	6.25	21.44
^{216}Th → ^{212}Ra	11.93	0.28	2.43E+09	1.77E+06	6.1E+23	23.78	1.65E-24	-23.7829	6.25	21.49
^{220}Th → ^{216}Ra	12.00	0.27	2.42E+09	1.76E+06	6.1E+23	23.78	1.65E-24	-23.7819	6.25	21.55
^{224}Th → ^{220}Ra	12.07	0.27	2.41E+09	1.76E+06	6.0E+23	23.78	1.66E-24	-23.7808	6.24	21.60
^{228}Th → ^{224}Ra	12.15	0.27	2.41E+09	1.75E+06	6.0E+23	23.78	1.66E-24	-23.7798	6.24	21.65
^{232}Th → ^{228}Ra	12.22	0.27	2.40E+09	1.75E+06	6.0E+23	23.78	1.66E-24	-23.7788	6.24	21.70
^{218}U → ^{214}Th	11.96	0.27	2.45E+09	1.78E+06	6.1E+23	23.79	1.63E-24	-23.7873	6.25	21.76
^{224}U → ^{220}Th	12.07	0.27	2.44E+09	1.78E+06	6.1E+23	23.79	1.64E-24	-23.7857	6.25	21.84
^{230}U → ^{226}Th	12.18	0.26	2.43E+09	1.77E+06	6.1E+23	23.78	1.64E-24	-23.7841	6.25	21.92
^{234}U → ^{230}Th	12.25	0.26	2.43E+09	1.77E+06	6.1E+23	23.78	1.65E-24	-23.7831	6.25	21.97
^{238}U → ^{234}Th	12.32	0.26	2.42E+09	1.76E+06	6.1E+23	23.78	1.65E-24	-23.7821	6.25	22.02
^{230}Pu → ^{226}U	12.18	0.26	2.46E+09	1.79E+06	6.2E+23	23.79	1.63E-24	-23.7889	6.25	22.16
^{234}Pu → ^{230}U	12.25	0.26	2.45E+09	1.79E+06	6.1E+23	23.79	1.63E-24	-23.7879	6.25	22.21
^{238}Pu → ^{234}U	12.32	0.26	2.45E+09	1.78E+06	6.1E+23	23.79	1.63E-24	-23.7869	6.25	22.27
^{242}Pu → ^{238}U	12.39	0.25	2.44E+09	1.78E+06	6.1E+23	23.79	1.64E-24	-23.7859	6.25	22.32
^{234}Cm → ^{230}Pu	12.25	0.25	2.48E+09	1.81E+06	6.2E+23	23.79	1.61E-24	-23.7926	6.26	22.45
^{238}Cm → ^{234}Pu	12.32	0.25	2.48E+09	1.80E+06	6.2E+23	23.79	1.62E-24	-23.7916	6.26	22.51
^{242}Cm → ^{238}Pu	12.39	0.25	2.47E+09	1.80E+06	6.2E+23	23.79	1.62E-24	-23.7906	6.25	22.56
^{246}Cm → ^{242}Pu	12.46	0.25	2.46E+09	1.79E+06	6.2E+23	23.79	1.62E-24	-23.7897	6.25	22.61
^{250}Cm → ^{246}Pu	12.53	0.25	2.46E+09	1.79E+06	6.1E+23	23.79	1.63E-24	-23.7887	6.25	22.66
^{240}Cf → ^{236}Cm	12.36	0.25	2.50E+09	1.82E+06	6.2E+23	23.80	1.60E-24	-23.7957	6.26	22.77
^{244}Cf → ^{240}Cm	12.43	0.25	2.49E+09	1.81E+06	6.2E+23	23.79	1.60E-24	-23.7947	6.26	22.82
^{248}Cf → ^{244}Cm	12.50	0.24	2.49E+09	1.81E+06	6.2E+23	23.79	1.61E-24	-23.7938	6.26	22.87
^{252}Cf → ^{248}Cm	12.57	0.24	2.48E+09	1.81E+06	6.2E+23	23.79	1.61E-24	-23.7928	6.26	22.92
^{256}Cf → ^{252}Cm	12.63	0.24	2.48E+09	1.80E+06	6.2E+23	23.79	1.61E-24	-23.7919	6.26	22.97
^{248}Fm → ^{244}Cf	12.50	0.24	2.51E+09	1.83E+06	6.3E+23	23.80	1.59E-24	-23.7982	6.26	23.11
^{254}Fm → ^{250}Cf	12.60	0.24	2.51E+09	1.82E+06	6.3E+23	23.80	1.60E-24	-23.7968	6.26	23.18
^{254}No → ^{250}Fm	12.60	0.23	2.53E+09	1.84E+06	6.3E+23	23.80	1.58E-24	-23.8012	6.27	23.42
^{258}No → ^{254}Fm	12.67	0.23	2.53E+09	1.84E+06	6.3E+23	23.80	1.58E-24	-23.8003	6.26	23.47
^{258}Rf → ^{254}No	12.67	0.23	2.55E+09	1.86E+06	6.4E+23	23.80	1.57E-24	-23.8046	6.27	23.70
^{260}Sg → ^{256}Rf	12.70	0.22	2.57E+09	1.87E+06	6.4E+23	23.81	1.55E-24	-23.8084	6.27	23.96
^{268}Hs→ ^{264}sg	12.83	0.22	2.59E+09	1.88E+06	6.5E+23	23.81	1.55E-24	-23.8107	6.27	24.29
^{270}Ds → ^{266}Hs	12.86	0.21	2.61E+09	1.90E+06	6.5E+23	23.81	1.53E-24	-23.8143	6.28	24.54
^{288}FI → ^{284}Cn	13.15	0.20	2.63E+09	1.92E+06	6.6E+23	23.82	1.52E-24	-23.8184	6.28	25.21
^{292}Lv→ ^{288}FI	13.21	0.20	2.65E+09	1.93E+06	6.6E+23	23.82	1.51E-24	-23.8214	6.29	25.48

Table 2: The table below shows different alpha transition of radioactive elements with constant frequency (n)

α *transition*	$L\,(fm)$	$Tsch$	$V(m/s)$	$\lambda\,(m)$	$log\lambda\,(m)$	n	$P = nT$	$LogP$	$t(s)$	$logt$	$Z/\sqrt{E}$
^{146}Sm→ ^{142}Nd	10.43	0.40	2.11E+09	1.54E+06	6.19	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	16.85
^{150}Gd→ ^{146}Sm	10.53	0.39	2.14E+09	1.56E+06	6.19	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	17.19
^{150}Dy→ ^{146}Gd	10.53	0.38	2.17E+09	1.58E+06	6.20	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	17.46
^{154}Dy→ ^{150}Gd	10.63	0.38	2.16E+09	1.58E+06	6.20	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	17.52
^{154}Er→ ^{150}Dy	10.63	0.37	2.20E+09	1.60E+06	6.20	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	17.80
^{154}Yb→ ^{150}Er	10.63	0.37	2.23E+09	1.62E+06	6.21	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.06
^{158}Yb→ ^{154}Er	10.72	0.36	2.22E+09	1.62E+06	6.21	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.12
^{158}Hf→^{154}Yb	10.72	0.36	2.26E+09	1.64E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.39
^{162}Hf→^{158}Yb	10.81	0.36	2.25E+09	1.64E+06	6.21	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.45
^{158}W→^{154}Hf	10.72	0.35	2.29E+09	1.67E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.65
^{162}W→^{158}Hf	10.81	0.35	2.28E+09	1.66E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.71
^{166}W→^{162}Hf	10.90	0.35	2.27E+09	1.65E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.77
^{180}W→^{176}Hf	11.21	0.34	2.25E+09	1.64E+06	6.21	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	18.97
^{166}Os→^{162}W	10.90	0.34	2.30E+09	1.68E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.03
^{170}Os→^{166}W	10.99	0.34	2.30E+09	1.67E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.09
^{174}Os→^{170}W	11.08	0.34	2.29E+09	1.67E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.15
^{166}Pt→^{162}Os	10.90	0.34	2.34E+09	1.70E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.29
^{172}Pt→^{168}Os	11.04	0.33	2.32E+09	1.69E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.38
^{176}Pt→^{172}Os	11.12	0.33	2.32E+09	1.69E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.44
^{180}Pt→^{176}Os	11.21	0.33	2.31E+09	1.68E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.49
^{184}Pt→^{180}Os	11.29	0.32	2.30E+09	1.68E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.55
^{188}Pt → ^{184}Os	11.38	0.32	2.30E+09	1.67E+06	6.22	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.61
^{172}Hg → ^{168}Pt	11.04	0.33	2.35E+09	1.71E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.63
^{176}Hg → ^{172}Pt	11.12	0.32	2.35E+09	1.71E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.69
^{180}Hg → ^{176}Pt	11.21	0.32	2.34E+09	1.70E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.75
^{184}Hg → ^{180}Pt	11.29	0.32	2.33E+09	1.70E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.81
^{188}Hg → ^{184}Pt	11.38	0.32	2.33E+09	1.69E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	19.86

$^{180}Pb \rightarrow {}^{176}Hg$	11.21	0.32	2.37E+09	1.73E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.00
$^{186}Pb \rightarrow {}^{182}Hg$	11.33	0.31	2.36E+09	1.72E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.09
$^{190}Pb \rightarrow {}^{186}Hg$	11.42	0.31	2.35E+09	1.71E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.15
$^{194}Pb \rightarrow {}^{190}Hg$	11.50	0.31	2.35E+09	1.71E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.20
$^{186}Po \rightarrow {}^{182}Hg$	11.33	0.31	2.39E+09	1.74E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.34
$^{194}Po \rightarrow {}^{190}Hg$	11.50	0.30	2.38E+09	1.73E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.45
$^{198}Po \rightarrow {}^{194}Hg$	11.58	0.30	2.37E+09	1.72E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.51
$^{202}Po \rightarrow {}^{198}Hg$	11.66	0.30	2.36E+09	1.72E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.56
$^{206}Po \rightarrow {}^{202}Hg$	11.73	0.29	2.36E+09	1.72E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.62
$^{210}Po \rightarrow {}^{206}Hg$	11.81	0.29	2.35E+09	1.71E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.67
$^{214}Po \rightarrow {}^{210}Hg$	11.89	0.29	2.35E+09	1.71E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.72
$^{218}Po \rightarrow {}^{214}Hg$	11.96	0.29	2.34E+09	1.70E+06	6.23	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.77
$^{196}Rn \rightarrow {}^{192}Po$	11.54	0.30	2.40E+09	1.75E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.73
$^{202}Rn \rightarrow {}^{198}Po$	11.66	0.29	2.39E+09	1.74E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.81
$^{206}Rn \rightarrow {}^{202}Po$	11.73	0.29	2.39E+09	1.74E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.87
$^{210}Rn \rightarrow {}^{206}Po$	11.81	0.29	2.38E+09	1.73E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.92
$^{214}Rn \rightarrow {}^{210}Po$	11.89	0.29	2.37E+09	1.73E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	20.97
$^{218}Rn \rightarrow {}^{214}Po$	11.96	0.28	2.37E+09	1.72E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.03
$^{222}Rn \rightarrow {}^{218}Po$	12.04	0.28	2.36E+09	1.72E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.08
$^{204}Ra \rightarrow {}^{200}Rn$	11.70	0.29	2.42E+09	1.76E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.09
$^{214}Ra \rightarrow {}^{210}Rn$	11.89	0.28	2.40E+09	1.75E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.22
$^{218}Ra \rightarrow {}^{214}Rn$	11.96	0.28	2.40E+09	1.74E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.27
$^{222}Ra \rightarrow {}^{218}Rn$	12.04	0.28	2.39E+09	1.74E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.33
$^{226}Ra \rightarrow {}^{222}Rn$	12.11	0.27	2.38E+09	1.74E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.38
$^{212}Th \rightarrow {}^{208}Ra$	11.85	0.28	2.43E+09	1.77E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.44
$^{216}Th \rightarrow {}^{212}Ra$	11.93	0.28	2.43E+09	1.77E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.49
$^{220}Th \rightarrow {}^{216}Ra$	12.00	0.27	2.42E+09	1.76E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.55
$^{224}Th \rightarrow {}^{220}Ra$	12.07	0.27	2.41E+09	1.76E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.60
$^{228}Th \rightarrow {}^{224}Ra$	12.15	0.27	2.41E+09	1.75E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.65
$^{232}Th \rightarrow {}^{228}Ra$	12.22	0.27	2.40E+09	1.75E+06	6.24	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.70
$^{218}U \rightarrow {}^{214Th}$	11.96	0.27	2.45E+09	1.78E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.76
$^{224}U \rightarrow {}^{220Th}$	12.07	0.27	2.44E+09	1.78E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.84
$^{230}U \rightarrow {}^{226Th}$	12.18	0.26	2.43E+09	1.77E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.92
$^{234}U \rightarrow {}^{230Th}$	12.25	0.26	2.43E+09	1.77E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	21.97
$^{238}U \rightarrow {}^{234Th}$	12.32	0.26	2.42E+09	1.76E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.02
$^{230}Pu \rightarrow {}^{226}U$	12.18	0.26	2.46E+09	1.79E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.16
$^{234}Pu \rightarrow {}^{230}U$	12.25	0.26	2.45E+09	1.79E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.21
$^{238}Pu \rightarrow {}^{234}U$	12.32	0.26	2.45E+09	1.78E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.27
$^{242}Pu \rightarrow {}^{238}U$	12.39	0.25	2.44E+09	1.78E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.32
$^{234}Cm \rightarrow {}^{230}Pu$	12.25	0.25	2.48E+09	1.81E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.45
$^{238}Cm \rightarrow {}^{234}Pu$	12.32	0.25	2.48E+09	1.80E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.51
$^{242}Cm \rightarrow {}^{238}Pu$	12.39	0.25	2.47E+09	1.80E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.56
$^{246}Cm \rightarrow {}^{242}Pu$	12.46	0.25	2.46E+09	1.79E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.61
$^{250}Cm \rightarrow {}^{246}Pu$	12.53	0.25	2.46E+09	1.79E+06	6.25	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.66
$^{240}Cf \rightarrow {}^{236}Cm$	12.36	0.25	2.50E+09	1.82E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.77
$^{244}Cf \rightarrow {}^{240}Cm$	12.43	0.25	2.49E+09	1.81E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.82
$^{248}Cf \rightarrow {}^{244}Cm$	12.50	0.24	2.49E+09	1.81E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.87
$^{252}Cf \rightarrow {}^{248}Cm$	12.57	0.24	2.48E+09	1.81E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.92
$^{256}Cf \rightarrow {}^{252}Cm$	12.63	0.24	2.48E+09	1.80E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	22.97
$^{248}Fm \rightarrow {}^{244}Cf$	12.50	0.24	2.51E+09	1.83E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	23.11
$^{254}Fm \rightarrow {}^{250}Cf$	12.60	0.24	2.51E+09	1.82E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	23.18
$^{254}No \rightarrow {}^{250}Fm$	12.60	0.23	2.53E+09	1.84E+06	6.27	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	23.42
$^{258}No \rightarrow {}^{254}Fm$	12.67	0.23	2.53E+09	1.84E+06	6.26	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	23.47
$^{258}Rf \rightarrow {}^{254}No$	12.67	0.23	2.55E+09	1.86E+06	6.27	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	23.70
$^{260}Sg \rightarrow {}^{256}Rf$	12.70	0.22	2.57E+09	1.87E+06	6.27	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	23.96
$^{268}Hs \rightarrow {}^{264}sg$	12.83	0.22	2.59E+09	1.88E+06	6.27	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	24.29
$^{270}Ds \rightarrow {}^{266}Hs$	12.86	0.21	2.61E+09	1.90E+06	6.28	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	24.54
$^{288}FI \rightarrow {}^{284}Cn$	13.15	0.20	2.63E+09	1.92E+06	6.28	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	25.21
$^{292}Lv \rightarrow {}^{288}FI$	13.21	0.20	2.65E+09	1.93E+06	6.29	4.5E+25	4.53E+25	25.66	2.21E-26	-25.6559	25.48