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Metastability of δΦ Configurations and the Physical Mechanism of Radioactive Decay

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Related documents: SMT Core v10.0; SMT Research No. 37; SMT Research No. 108

Introduction

Radioactive decay is traditionally interpreted in quantum mechanics as a fundamentally probabilistic process associated with the tunneling of wave functions through potential barriers. Despite the high accuracy of empirical decay laws, the physical mechanism underlying them remains phenomenological: transition probabilities are introduced postulatively, and characteristic lifetimes are considered as independent parameters.

Within the framework of Medium Theory (SMT), this interpretation is considered incomplete. SMT describes physical reality as a continuous nonlinear medium Φ, whose dynamics are given by the kinetic functional K(X) and the potential V(\Phi). Particles and nuclei correspond to localized configurations and topological defects of this medium.

In this picture, radioactive decay is not a fundamental accident, but a dynamic process of relaxation of metastable configurations of the medium through the energy barriers of a nonlinear landscape.

The purpose of this work is to show that:

- $\delta\Phi$ configurations of nuclei are metastable minima of the energy of the medium Φ
- finite energy barriers ΔV are formed between them
- the restructuring of the medium occurs through relaxation attempts with a fundamental time τ_{relax}
- the exponential decay law arises as a universal consequence of this dynamics
- the lifetimes of nuclei are determined by the geometry of configurations and the parameters of the medium

Dynamics of the Medium Φ in Core v10 and the Formation of Energy Barriers

In SMT Core v10, the kinetics of the medium are given by the expression:

$$K(X) = X + \frac{\beta X^2}{\Lambda_k^4}$$

where

$$X = \frac{1}{2} \partial_\mu\Phi \, \partial^\mu\Phi$$

β is a dimensionless nonlinearity coefficient, and Λ_k is the elasticity scale of the medium.

The nonlinear term $\beta X^2/\Lambda_k^4$ provides resistance of the medium to strong deformations and leads to the formation of stable and metastable localized configurations.

When attempting to restructure the $\delta\Phi$ configuration, there is an increase in energy density associated with both kinetic nonlinearity and the potential part $V(\Phi)$. This forms an energy barrier between states:

$$\Delta V \approx \int \left[\frac{\beta X^2}{\Lambda_k^4} + \Delta V_{\text{pot}}(\Phi) \right] d^3x$$

Thus, the decay barrier is not arbitrary — it directly follows from the Core v10 parameters and the geometry of the configuration.

Correlation Length of the Medium and Fundamental Relaxation Time

Small perturbations of the medium Φ propagate at a speed:

$$c_s^2 = \frac{K_X}{K_X + 2XK_{XX}}$$

For the Core v10 kinetics form:

$$c_s^2 = \frac{1 + 2\beta X/\Lambda_k^4}{1 + 6\beta X/\Lambda_k^4}$$

This ensures the hyperbolicity of the equations and the finite speed of disturbance propagation.

The characteristic correlation length of the medium is determined by the effective mass:

$$\ell_\Phi \approx \frac{1}{m_{\text{eff}}}$$

$$m_{\text{eff}}^2 = V''(\Phi_0)$$

Accordingly, the fundamental relaxation time is:

$$\tau_{\text{relax}} \approx \frac{\ell_\Phi}{c_s}$$

As shown in SMT Research No. 37, it is this time that sets the scale of all processes of medium restructuring.

Relaxation Mechanism of Radioactive Decay

The metastable $\delta\Phi$ configuration is continuously subjected to environment fluctuations.*

Each fluctuation initiates a local attempt at rearrangement on the scale of ℓ_Φ.

During time t, the number of independent relaxation attempts is:

$$N(t) = \frac{t}{\tau_{\text{relax}}}$$

With a low probability of overcoming the barrier in a single attempt $p \ll 1$, the total probability of decay obeys Poisson statistics:

$$P_{\text{surv}}(t) = \lim_{N\to\infty} (1 - p)^{N(t)} = \exp\left(-\frac{pt}{\tau_{\text{relax}}}\right)$$

Hence, the characteristic lifetime is:

$$T = \frac{\tau_{\text{relax}}}{p} = \tau_{\text{relax}} \cdot \exp\left(\frac{\Delta V}{E_f}\right)$$

Thus, the exponential decay law is a universal consequence of the relaxation dynamics of the medium Φ.

*Fluctuations of the medium are understood as nonlinear oscillations of the field Φ on the scale of the correlation length ℓ_Φ, caused by the dynamics of the kinetic functional Core v10, and not by the quantum uncertainty of wave functions in standard quantum mechanics.

Geometric Channels of Instability

The energy barrier ΔV is determined by the minimum path of rearrangement in the configuration space Φ:

$$\Delta V_{\text{eff}} = \min_{\text{path}} \Delta V(\text{path})$$

Main scenarios:
- local node deformations
- phase rearrangements
- formation of overloads
- separation of subconfigurations

As the complexity of configurations increases, the number of decay channels increases and the minimum barrier decreases.

Origin of Empirical Half-Life Laws

Since:

$$T = \tau_{\text{relax}} \cdot \exp\left(\frac{\Delta V_{\text{eff}}}{E_f}\right)$$

the logarithm of the lifetime is linearly dependent on the parameters affecting the barrier.

Empirical formulas of the form:

$$\log(T) = aF + b$$

arise as a reflection of the dependence of ΔV_{eff} on geometric and charge factors.

The coefficients a and b have physical meaning:

$$a \propto \frac{\kappa}{E_f}$$

$$b \propto \frac{\Delta V_0}{E_f} + \log(\tau_{\text{relax}})$$

Estimation of Lifetime Scales

The characteristic values of the energy barrier for $\delta\Phi$ configurations of nuclei are determined by the nonlinear elasticity of the medium:

$$\Delta V \sim \frac{\beta X^2 V_{\text{eff}}}{\Lambda_k^4}$$

where V_{eff} is the effective rearrangement volume.

Even for moderate values of β and X, the ratio $\Delta V/E_f$ naturally takes values of the order of 10–100 and above, which leads to an exponential spread of lifetimes:

$$T \sim \tau_{\text{relax}} \cdot \exp(10 - 100)$$

This explains the wide range of observed half-lives — from fractions of a second to billions of years — without introducing independent parameters for each isotope.

Universality of Half-Life

The parameters τ_{relax}, ΔV_{eff}, and E_f are formed on the microscopic scales of the medium Φ and are almost insensitive to macroscopic influences.

Therefore, decay is an intrinsic property of the configuration and is weakly dependent on external conditions.

Topological Stability and Connection with No. 108

Metastable nuclei belong to the same topological sector and allow for continuous rearrangement paths.

Topologically protected configurations (e.g., a proton with $|Q|\approx 1$) have no admissible relaxation path:

$$\Delta V \to \infty \quad \Rightarrow \quad T \to \infty$$

This explains the absolute stability of the proton without additional postulates.

SMT Predictions

- finiteness of the region of stable nuclei
- existence of islands of long-lived isotopes
- geometric criteria for stability
- possibility of controlled metastability in extreme modes

Conclusion

Radioactive decay in SMT is a dynamic process of relaxation of a nonlinear medium Φ.

The exponential decay law, differences in the lifetimes of elements, and particle stability are given a unified physical explanation through:

- nonlinear kinetics Core v10
- geometry of $\delta\Phi$ configurations
- fundamental relaxation time τ_{relax}

Decay ceases to be a fundamental accident and becomes a natural consequence of the dynamics of the medium.

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