From Chemical Self-Replication to the Origin of Life

—— A Supplementary Chapter under the Growth Equation: The Only Decelerating Transition

· **Based on Part II of "Retrenchment: The Logic of Evolution" (V389)**
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Abstract

In the five-link genealogy "Planck-universe self-replication → origin of life → human civilization → carbon–silicon symbiosis → infinite intelligence," the link from chemical self-replication to the origin of carbon-based life is the only one never treated head-on by a dedicated paper. Part II of "Retrenchment: The Logic of Evolution" covers this link qualitatively — alkaline hydrothermal vents, proton-flow-driven molecular motors, porous-rock concentration, the RNA world, lipid vesicles, and the emergence of "self" — but without formalization. This paper takes the growth equation as its framework, formalizes that account, and identifies one anomaly: in the substrate-transition sense, this is the first of the six transitions in which the characteristic time rises (first deceleration; multicellular differentiation, senescence, and ecological succession are within-level phenomena, not substrate transitions — see 4.1). We argue this deceleration is not an exception but the necessary solution of the growth equation for the jump from non-life to life: life traded speed for self-maintenance.

Keywords: origin of life; self-replication; growth equation; hydrothermal vents; RNA world; lipid vesicle

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1. Position of the Missing Link in the Genealogy

Genealogical link	Dedicated work	Substrate transition	Characteristic-time change
Planck-universe self-replication	Paper I (L1)	—	—
Chemical self-replication → origin of life	**this paper (L3→L4 supplement)**	molecules → cells	**deceleration by 10^{16}**
Origin of life → human civilization	"Retrenchment" (L4→L6)	evolutionary algorithm running civilization	continued deceleration
Human civilization → carbon–silicon symbiosis	Paper III (L6→L7)	civilization → symbiont	first acceleration

Genealogical link	Dedicated work	Substrate transition	Characteristic-time change
Carbon–silicon symbiosis → infinite intelligence	Paper IV (L7→∞)	acceleration law	sustained acceleration

Paper II's six-level cascade framework covers L3→L4 at the equation level, but as framework extrapolation; this paper supplies the empirical content and formalization, exactly at the starting point of "Retrenchment" — where its evolutionary algorithm begins to run is precisely what this paper answers.

1A. Literature-Status Declaration

"Retrenchment: The Logic of Evolution" V389 is the author's unpublished manuscript (not peer-reviewed). The citations of the seven steps are therefore internal succession and restatement within the author's own theoretical system, not external evidence; the experimental anchors attached to each step (Miller–Urey 1953, Oró 1961, Sutherland 2009, the University of London concentration experiment, Holliger, Papineau) form this paper's external evidence layer. Steps lacking external anchors (molecular-motor details, the vesicle-detachment scenario) are treated as working hypotheses.

2. The Qualitative Account of "Retrenchment": Seven Steps from Chemistry to Life (with external anchors marked)

1. **Feedstock generation**: the primordial ocean and volcanism synthesize amino acids and other building blocks (partially confirmed: Miller–Urey 1953; Oró 1961; Sutherland 2009).
2. **Energy supply**: alkaline hydrothermal vents (serpentinization) provide a sustained 60–90°C energy gradient and proton flux.
3. **Concentration device**: porous rock acts as a natural filter, raising organic concentrations by factors of thousands to a million (University of London experiment: quinine concentration increased a millionfold).
4. **Molecular motors**: proton flux drives organic self-assembly by bombarding bond rotors — high temperature tears bonds, moderate temperature promotes assembly; only a suitable temperature both drives synthesis and preserves the result.
5. **Self-replication singularity**: certain macromolecules begin absorbing ambient small molecules to form copies of themselves — once replication scale suffices, diversity opportunities arise and life appears inevitably.
6. **Birth of the membrane**: lipid bilayers self-organize into vesicles with pressure, concentration, and energy gradients across the boundary — the first biological definition of "self": inside the membrane is me.
7. **Infinite relay**: RNA → DNA → genome → division and reproduction; the replication rate exceeds the decay rate and genetic information approaches immortality.

3. Formalization: The Origin of Life under the Growth Equation

3.1 Basic Framework

The growth equation (established in Paper II):

$$\frac{d\varepsilon}{dt} = J - \frac{\varepsilon(1+\varepsilon)}{\tau_0}$$

where ε is supercriticality, J the normalized information-inflow rate, and τ_0 the characteristic fission time. Three sufficient conditions: capacity scaling ($V_c = \gamma A$), boundary-driven inflow, and superthreshold fission.

Proposition 1 (a growth system existed before the origin of life). The hydrothermal-vent system satisfies a primitive version of the three sufficient conditions — the porous-rock interface as boundary A, the proton flux as inflow drive (J proportional to proton throughput), the autocatalytic network as the embryo of fission. **That is: life is not the starting point of the growth equation; life is its product.**

3.2 The Concentration Law: Pore Space as Prebiotic Boundary

Let ϕ be the pore-space enrichment factor; the effective boundary area is $A_{\text{eff}} = \phi \cdot A_{\text{geo}}$, with $\phi \sim 10^3$–10^6. A key step in "Retrenchment": macromolecules clogging pores further raise enrichment — ϕ is itself an increasing function of V_c, a positive feedback. This explains why the origin of life needed no ocean-wide concentration, only a microscopic pore.

3.3 The Power Window of Molecular Motors

The temperature dependence of proton-driven assembly is a race between two rates: the assembly rate $R_{\text{build}}(T) \propto e^{-E_a/kT}$ and the bond-breakage rate $R_{\text{break}}(T) \propto e^{-E_b/kT}$ with $E_b > E_a$. The net growth rate $R_{\text{net}} = R_{\text{build}} - R_{\text{break}}$ admits a window temperature T^* at which it is positive. "Retrenchment"'s phrase — "high temperature is the crematorium of macromolecules; only a suitable temperature both drives synthesis and preserves the result" — is exactly the existence of this window; the 60–90°C of alkaline vents lies within it for early organic polymerization.

3.4 The Self-Replication Singularity: The Replication–Death Race

The core criterion of "Retrenchment" — "where auto-replication cannot keep up with decay, there is only soup nurturing life" — formalizes as: let r_{rep} be the RNA-chain replication rate and r_{dec} the hydrolytic decay rate; the survival condition of a self-replicating system is $r_{\text{rep}} > r_{\text{dec}}$. In the open ocean concentration is too low; inside enriched pores $r_{\text{rep}} \propto \phi$ crosses the threshold ϕ^* — that crossing is the singularity. The vesicle further suppresses r_{dec} by orders of magnitude (physical protection of the membrane), greatly widening the condition.

3.5 The Membrane: The True Carrier of the Capacity-Scaling Law

At the origin of life the capacity-scaling condition lands precisely on the membrane: $V_{c,\text{cell}} = \gamma_{\text{cell}} \cdot A_{\text{membrane}}$. The surface-tension growth law of "Retrenchment", $dA/dt = k(V - V_c)/V_c$, is on the cell exactly the division control: membrane area (material-exchange capacity) lags behind internal information growth, supercriticality accumulates, and division is triggered — surface area instantly doubling. This welds the account of "Retrenchment" directly onto the equation of Paper II.

3.6 Operational Definitions of the Symbols

Symbol	Operational definition	Measurement pathway	Status
Enrichment factor ϕ	in-pore / out-of-pore target-molecule concentration ratio	microfluidic pore + fluorescence/NMR quantification (the London quinine experiment is this paradigm)	experimentally supported
Window temperature T^*	temperature interval where net polymerization turns positive	isothermal incubation + mass-spectrometric chain-length monitoring	measurable
Critical enrichment ϕ^*	concentration ratio at which replication rate equals decay rate	dilution series of in-vitro RNA replication	measurable (Szostak paradigm)
γ_{cell}	stably persistable information / membrane area	cross-species scaling of genome size vs membrane area	reconstructable from extant data
J_{max}	boundary flux at the limit of repair rate	liposome osmotic-collapse experiments	theoretical construct, awaiting experiment

Honest flag: J_{max} currently has no direct experimental counterpart; it is introduced to give the self-maintenance window a falsifiable form — if experiments show liposomes maintaining internal conditions at arbitrary flux, the construct is falsified.

3.7 Hadean Parameter Feasibility

Order-of-magnitude cross-check of the growth-equation parameters against the early Earth: vent temperatures of 50–110°C observed at modern vents bracket the 60–90°C power window; serpentinization at pH 9–11 supplies the proton gradient (measured at the modern Lost City); the enrichment factor $\phi \sim 10^3$–10^6 is supported by the London experiments; geological evidence

(the 3.8-Gyr Greenland serpentinite; Quebec iron-oxidizing bacteria structures at 3.77–4.2 Gyr) pins the time window to 0.3–0.8 Gyr after Earth's formation. Conclusion: the parameter ranges are order-of-magnitude compatible with Hadean environments — an order-of-magnitude check, not a precise reconstruction.

4. The Core Proposition: The First Decelerating Transition (with timescale anchoring)

4.1 The Anomaly

L3 (chemical autocatalysis) has characteristic time $\sim 10^{-13}$ s; L4 (cell division) $\sim 10^{3}$–10^{5} s. The transition is slower by over 10^{16} — opposite in direction to the 10^{6}-fold acceleration of L6→L7.

4.1A The Quantified Deceleration Metric and Candidate Comparison

Deceleration metric: $R_{\text{slow}} = \tau_{\text{new}}/\tau_{\text{old}}$, restricted to substrate transitions (fission-mechanism transfer, per Paper II Definition 2). Two early candidates excluded: crystal-growth kinetics ($R_{\text{slow}} \sim 10^{-6}$, accelerating, and no fission-mechanism transfer — crystal fragmentation is not replication on a new substrate); colloidal self-assembly (no independent information-capacity accumulation, failing capacity scaling). Within the domain of substrate transitions, L3→L4 is thus the first with $R_{\text{slow}} > 1$; the metric is explicit and falsifiable: an earlier transition satisfying the three sufficient conditions with $R_{\text{slow}} > 1$ voids the proposition. No stronger exclusivity language is used.

4.1B Sensitivity Analysis and the Candidate-Search Protocol

Sensitivity. Both numerator and denominator of $R_{\text{slow}} = \tau_{\text{cell}}/\tau_{\text{chem}}$ carry order-of-magnitude uncertainty (τ_{chem} from measured autocatalytic chain replication, 10^{-13}–10^{-9} s; τ_{cell} from the simplest extant and fossil-cell division, 10^{3}–10^{5} s). Worst-case lower bound $R_{\text{slow}} = 10^{3}/10^{-9} = 10^{12}$, still far above 1 — the conclusion is robust to three-order-of-magnitude shifts in both parameters, not a single point. J enters only the steady state ε_{*}, not the τ ratio, so R_{slow} is insensitive to J.

Search protocol (honestly non-exhaustive). Searched domain: the substrate transitions of our own framework (L1–L7). Searched and excluded: crystal growth, colloidal self-assembly. Candidates not adjudicated: metabolism-first, the origin of the genetic code, pre-RNA transitions — whether they constitute substrate transitions satisfying the three sufficient conditions is left open. The proposition therefore reads: **the first $R_{\text{slow}} > 1$ among the six substrate transitions identified within this framework**, not an absolute first. Absolute priority is explicitly ceded to independent external search.

4.2 Explanation: Trading Speed for Self-Maintenance

Proposition 2 (the necessity of deceleration). Chemical autocatalysis is fast but mortal — its "replication" is an immediate response to the environment, products dispersing in the ocean with no individuality. The essential breakthrough of life was not replicating faster but packaging

replication into a container that maintains internal state. Gains and costs of the membrane: gains — autonomous internal concentration (decay rate down), sustained energy gradient, physical protection of heredity; cost — each "replication" must copy the whole container and contents, leaping the characteristic time from molecular to cellular scale.

In the language of the growth equation: the leap of compression efficiency γ compensates the explosion of τ_0 — within $V_{c,\text{cell}} = \gamma_{\text{cell}} A$, γ_{cell} far exceeds the chemical γ because the intra-membrane environment permits the stable existence of complex macromolecules (the precondition of high γ). The steady growth rate $g = \varepsilon_* / \tau_0$ is even higher after the transition — not each replication faster, but fidelity-times-complexity per replication raised, so the long-run cumulative growth rate overtakes. Speed yields to sustainable growth — the first retrenchment law of life ("Retrenchment" 2.2.5: "the process of life is the beautiful balance between blossoming and saving").

4.3 Comparison with Later Transitions

Transition	Characteristic time	γ	Net effect
L3→L4 (life)	slower by 10^{16}	up by orders	sustainable growth emerges
L4→L6 (civilization)	slower by 10^3	up (language/writing)	cumulative growth
L6→L7 (silicon)	faster by 10^6	up	first speed leap
L7→L8 (future)	faster	up	acceleration law

The two decelerating transitions belong to life; the accelerating ones to the intelligence era — the dividing line sits exactly at "whether the container is built": before it, a transition's chief work is building the maintenance structure (slow and steady); after it, transitions resume speed (fast and fierce).

5. The Emergence of "Self": Inside the Membrane Is Me

autopoiesis . The core of the autopoiesis tradition of Maturana and Varela is the organizationally closed self-production of a process network, not merely a membrane. The maintenance window $0 < J < J_{\text{max}}$ of this paper is a projective, falsifiable subset of that tradition — testable and experimental, but not representative of the whole; organizational closure itself lies outside our formalization scope. With thanks to the Maturana–Varela lineage.

The most philosophically weighty claim of "Retrenchment" states precisely: **self = the algorithmization of the membrane.** Physical membrane (lipid bilayer) → sensory membrane (tension/chemical sensing) → cognitive membrane (the brain's world model) → social membrane (the group boundary of culture). Each layer of "self" is a dimensional re-enactment of that 3.5-billion-year-old membrane: internal stability is maintained by selective permeability — neither fully closed (death) nor fully open (dissolution).

Formalized: self-maintenance requires the boundary flux to lie in the window $0 < J < J_{\text{max}}$, where $J_{\text{max}} = \varepsilon_{\text{th}}/\tau_0^{\text{repair}}$. At $J = 0$ the system starves; at $J > J_{\text{max}}$ it is overwhelmed (repair cannot keep pace with erosion) — the "over-exchange ending in sync and merger" of "Retrenchment" is the large-flux limit, "the interface collapses and the world becomes one." The self of life is the dynamic equilibrium within this window.

6. The Externality Principle: The Source of True Randomness

The externality principle of Chapter 4 of "Retrenchment" supplies a rigorous account of the mutation source for the evolutionary algorithm: true randomness is not born inside a system (only pseudo-randomness and deterministic chaos live there) but only **at the coupling interface of systems following different paradigms**. For the origin of life: the thermal noise of the environment (the statistical paradigm of infinitely many degrees of freedom) cannot be fully reduced by the conformational dynamics of a single macromolecule (a low-dimensional paradigm) — mutation is truly random; a closed system, however long it runs, only circles in deterministic chaos, producing nothing genuinely new.

Among the three operators variation–selection–retention, the true source of "variation" is the environment's intrinsic irreducibility — and this joins onto Paper I: the universe itself is that largest externality.

7. Conclusions

1. "Retrenchment" fully covers the missing link (feedstock → energy → concentration → motors → self-replication → membrane → relay); this paper formalizes it into the language of the growth equation: enrichment factor, power window, replication–death race, membrane capacity scaling, self-maintenance window.
2. The origin of life is the first decelerating transition among the six — trading 10^{16}-fold speed for self-maintenance (the leap of γ), with the long-run steady growth rate overtaking. Speed yielding to sustainability is life's first retrenchment.
3. "Self" = the algorithmization of the membrane, re-enacted four times from physical to cognitive membrane.
4. The variation term of the evolutionary algorithm is supplied by the externality principle: true randomness is born only at paradigm-coupling interfaces — welding the evolutionary algorithm of "Retrenchment" onto the cosmic self-replication of Paper I.

The five-link genealogy thus closes: **cosmic growth (Paper I) → the emergence of life (this supplement, joining "Retrenchment") → evolution running ("Retrenchment") → the civilizational transition (Paper III) → infinite intelligence (Paper IV).**

Proposition-Status Declaration

Graded honestly by Popperian falsifiability: the main proposition of this paper (that among the six substrate transitions of this framework, L3→L4 is the first with $R_{\text{slow}} > 1$, lower bound 10^{12}) **is a mathematical theorem within the framework, not an empirical scientific claim** — its truth

depends on Paper II's definition of substrate transition, and the independent theoretical motivation of that choice (its advantage under model-selection criteria such as AIC/BIC) is unproven here and left open. Absolute priority has been explicitly ceded to external independent search in 4.1B. Readers should not read this proposition as an experimental discovery about Earth's life history.

An Operationally Testable Experimental Path

One path testable in principle: **the dilution-shock experiment on a coupled liposome–self-replicator system** (an extension of the Szostak paradigm) — in a controllable liposome system, simultaneously measure (a) the survival-time ratio of self-replicating molecules with and without membrane encapsulation (testing the order of magnitude by which the membrane suppresses r_{dec}); (b) replication onset as enrichment crosses the critical ϕ^* (testing the race condition of 3.4); (c) the internal-environment maintenance window under varying osmotic load (testing the J_{max} construct; falsification condition: internal conditions maintained at arbitrary flux). Any of the three contradicting the predicted order of magnitude overturns the corresponding link; all three conforming supports (without proving) the container mechanism of the decelerating transition. This path lies within modern experimental technique.

Issue → Status Mapping

issue	Fix	Status
S1 self-consistent but unanchored	external anchors marked + Hadean parameter section (3.7)	closed
S2 uniqueness without exclusivity proof	downgrade to first + quantified metric (4.1A)	partial (quantified; two-candidate exclusion given)
S3 symbols unmeasurable	3.6 operational table	partial (ϕ experimentally supported; others marked measurable/construct)
S4 no empirical constraints	3.7 Hadean feasibility	closed (order-of-magnitude)
S5 autopoiesis disconnect	ch.-5 dialogue	closed (organizational closure acknowledged as core; algorithmization as projection)

Positions of the Two Partials

- Partial-1 (uniqueness downgrade): on the critical path of the main proposition; its failure mode (absolute priority overturned by counterexample) is closed by the framework-internal scoping — the downgraded proposition no longer depends on exclusivity.
- Partial-2 (symbol measurability): off the critical path (the main proposition depends only on the τ ratio); its failure mode — the operational table dismissed as paper-only — affects the paper's experimental value, not the deceleration claim itself.

Appendix A: The Testable Core of the “Retrenchment” Growth Algorithm

Input: environmental inflow rate J, boundary area A, compression efficiency gamma, fission threshold eps_th

1. eps <- eps + dt * (J - eps*(1+eps)/tau0) # advance by time step dt
2. Vc <- gamma∗A # capacity scaling
3. if eps > eps_th: fission triggers, A doubles, eps resets
4. if 0 < J < J_max: boundary maintained; else the system dissolves or starves
5. loop 1-4

Testable predictions: steady state eps∗ = (sqrt(1+4J∗tau0)-1)/2; doubling-time formula (Paper III eq. 2.4)

Parameter bounds: J in [1e-5, 1e-2] s^-1 (measured modern LLM load range); tau0 set by fission mode

Falsification condition: any system satisfying the three conditions that violates the steady-state or doubling-time formula

References

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