

The Circle That Remembers, the Interval That Forgets

GG-Theory and the Sixteen Problems of Particle Physics and Cosmology

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Abstract

Physics keeps a short list of questions its own tools cannot close: what happens when a measurement happens; where the Standard Model's two dozen unexplained numbers come from; what launched the Big Bang; what became of the information that fell into a black hole. Their median age is seventy years.

This paper takes sixteen of them and follows one exact, elementary statement to all sixteen. In the six-dimensional geometry of GG-Theory, every point of ordinary space carries two further directions of opposite kind: a closed circle and an open interval. A holonomy — the record a loop keeps of what happened around it, the quantity all of gauge physics is built from — requires closed loops, and an interval has none. Everything on the circle is therefore holonomy: quantized, protected, reversible, a group. Nothing on the interval can be: its transport runs forward only, a semigroup, and each step is final. *The circle remembers; the interval forgets.*

Read with the cohort's open-system chain, that sentence sorts all sixteen. A measurement is the interval writing what the circle carried; gauge invariance is the circle's unreadability and renormalization is motion along the interval; time's tick is the circle's and its direction the interval's; the black hole's information was never lost, only billed to the wrong book. Nothing is newly derived here: every result is proved in a cohort paper and carried at its parent's declared grade, with conditional and flagged claims marked in place. The paper closes with the named measurements on which six of the sixteen treatments die outright, and with how the other ten are exposed through the ledger they share.

Executive Summary

The list. Every working physicist carries a version of the same list: the questions the discipline has not closed. It is shorter than outsiders expect and older than insiders like to admit. The measurement problem was posed in the 1920s and sharpened in 1935; dark matter was inferred in 1933; the strong- CP problem and the black-hole information paradox both date from 1976; the hierarchy problem from 1979; the cosmological constant problem was already notorious when the acceleration was found in 1998. Four decades of colliders, telescopes, and theory programs have sharpened every entry and closed almost none. The standard response has been to attack them one at a time, each with its own tool — an interpretation for measurement, a symmetry for the hierarchy, a new particle for the dark sector, an ensemble of universes for the constants. This paper does the opposite: it asks whether the list is long because the questions are many, or because one structural fact about the world is missing from all of them.

The one sentence. Walk around a closed circuit carrying an arrow and holding it as steadily as the geometry allows; when you return, the arrow may have turned. That turning is a *holonomy*: the record a loop keeps of what happened around it, and the quantity that all of gauge physics is built from. It requires a loop. In the six-dimensional bulk of **GG-Theory**, the two non-spatial directions are fibers of opposite kind: a compact circle S^1_θ , on which every path closes, and an open scale interval I_r , on which none does. So *holonomy requires closed loops, and an interval has none*. Everything on the circle is holonomy — quantized, gauge-protected, reversible, a group. Nothing on the interval can be: its transport composes forward only, a semigroup, and each step is final. *The circle remembers; the interval forgets*. That is the whole instrument.

Why exactly one of each. A bulk with two circles would conserve everything and decide nothing: no arrow, no record, no outcome — a world that *is* but never *becomes*. A bulk with two intervals would decide everything and keep nothing: no quantized charge, no stable atom, no interference — a world that *becomes* but never *is*. Being needs holonomies; becoming needs a semigroup. One fiber of each kind is the constitutional minimum, and it is what the program's axioms write.

What the sentence organizes. Sixteen problems, in four groups. The numbers below are the cohort's, produced by its derivations; what the sentence supplies is the sorting that makes them one story. *The Standard Model*: a measurement is the interval writing what the circle carried, which is why one theory needed two dynamics; gauge invariance is the circle's unreadability and renormalization is motion along the interval; the parameter sheet is a codebook in one alphabet — $\alpha^{-1}(0) = 2^J + N^2 = 137$, $\sin^2 \theta_W = L^2/(4N^3)$, $v = M_{\text{lock}}(2/L)^N = 246.3$ GeV. *Cosmology*: the Big Bang becomes a launch that is derived, not chosen ($n_s = 0.9634$, $r = 0.0038$); the hierarchy is not a small number but a deep one ($K = 35$ e-folds of descent); the dark trio is the two fibers in the sky — inflation the interval's coordinate rolling once, the Kaxion the circle's still ringing at $8.1 \mu\text{eV}$ and 1.95 GHz, dark energy both at rest. *The foundation of particle physics*: C , P , and T are the geometry's three orientation choices, and their observed fates follow by fiber — CPT exact, CP broken, T broken at runtime; an antiparticle is the same class read in the mirror, and the matter excess is a one-way toll of $e^{-K/2}$, giving $\eta_B = 5.9 \times 10^{-10}$ against a measured 6.1×10^{-10} ; quarks confine because three color steps close a loop, and the proton is stable because baryon number is a

gauged holonomy class and the geometry has no $\Delta B = 1$ aperture. *The foundation of the cosmos:* time's tick is the circle's and its arrow the interval's, with the chronology exact ($d \ln t / dr = 2$; an age ledger closing at 140.24); energy is what a tick is worth and entropy is what the arrow has read; the multiverse is not refuted but unemployed; and the black hole's information was always in the books, on the other page.

Where the sentence comes from. The anatomy is not an interpretive overlay placed on the cohort after the fact; it is the arena the cohort's own axioms force, read back in plain language. The program is built in four steps. *Step (A)* writes the bulk: the constitutional charter of four axioms and seven postulates (Arisaka, 2026, A1-Constitution), the geometry–gauge locking that forces $\mathcal{M}_6 = \mathcal{M}_4 \times I_r \times S_\theta^1$ with $\text{Spin}(1, 5) \times SU(5) \times U(1)_B \times U(1)_{Qi}$ (Arisaka, 2026, A2-GG6), the anomaly closure that fixes the ledger's coefficient arithmetic (Arisaka, 2026, A3-BI6), and the Euclidean input discipline that leaves zero free continuous parameters (Arisaka, 2026, A4-Euclid). *Step (B)* writes the projection: the open-system dynamics that makes observation a marginalization of the fiber coordinates (Arisaka, 2026, A5-GDOS), the cascade engine that runs it (Arisaka, 2026, A6-GRIP), and the quantum-information backbone that meters it (Arisaka, 2026, A7-Qi4). *Step (C)* spends the machinery on the world: quantum mechanics (Arisaka, 2026, A8-QM), the Standard Model (Arisaka, 2026, A9-SM), Λ CDM (Arisaka, 2026, A10-Cosmos), and the origin of life and mind (Arisaka, 2026, A11-Origin). *Step (D)* is the pair of white papers: GG-W1-Symmetry walked a century of symmetry and conservation to the point where protection stops needing a symmetry (Arisaka, 2026, W1-Symmetry); this one takes the two fibers and walks them into the sixteen problems.

The ledger the numbers are written in. Five integers $(M, N, L; J, K) = (1, 3, 5; 7, 35)$, with $J = 2N + 1$ and $K = LJ$, carry the circle's side of the accounting; depths along the interval carry the rest. From them the cohort's closed forms follow with nothing left to adjust: $\alpha^{-1}(0) = 2^7 + 3^2 = 137$, $\sin^2 \theta_W = 5^2 / (4 \cdot 3^3) = 0.23148$, $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} = 3.849 \text{ TeV}$, $v = M_{\text{lock}} (2/5)^3 = 246.3 \text{ GeV}$ (Arisaka, 2026, A9-SM); $\Omega_m = 1/\pi$ and $\Omega_b = 1/(2\pi^2)$, $n_s = 0.9634$ and $r = 0.0038$ at a derived $N^* = 52.6$ (Arisaka, 2026, A10-Cosmos); the Kaxion at $8.1 \mu\text{eV}$ and 1.95 GHz (Arisaka, 2026, C1-Kaxion); $d \ln t / dr = 2$ exactly, and a black-hole ledger that returns the Page curve rather than postulating it (Arisaka, 2026, C3-BH). Each is quoted here at its parent paper's grade — derived, derived-conditional, named input, postulated, or flagged — and the grades are printed beside the numbers rather than in a footnote.

What this paper is, and is not. It is a synthesis, not a new derivation. Every equation, number, and theorem carried here is proved in a cohort paper — chiefly GG-W1-Symmetry, GG-P5-CPT, GG-P6-Proton, GG-A10-Cosmos, GG-C1-Kaxion, and GG-A8-QM — and is cited at first use and carried at its parent's grade, with every conditional and flagged claim marked in place. The paper's own contribution is the anatomy that makes them one story, and the exposure that follows: Part VII collects, in one table, the named measurements on which six of the sixteen treatments die outright, and states how the other ten are exposed through the ledger all sixteen share. A reader who wants the argument in an hour should read Part I, Part II, and the Conclusions; a reader who wants to attack it should read Part II and then the falsifier table.

What the back of the paper is for. Three Parts follow the argument, and none of them is an appendix in the ordinary sense. Part IX is a graduate course: nine topics, each in four steps — what the standard textbooks establish and how they establish it, why the problem nevertheless survives, how the two fibers address it with the mathematics written out, and worked problems with solutions. It is meant to be self-sufficient, so that an incoming graduate student can learn the standard material and the framework’s reading of it from the same pages, and it opens with a reading list naming the textbooks and the original papers for each topic. Part X collects one hundred and seventeen objections — the questions the author has actually been asked, sharpened — and answers them, beginning with twenty-two from the curious reader before any specialist gets a turn. Part XI is a bibliography in which every entry carries a paragraph saying what the work established, what it cost the field, and where this paper’s reading departs from it. A framework asking to be taken seriously owes its readers the means to check it, and these three Parts are that debt paid.

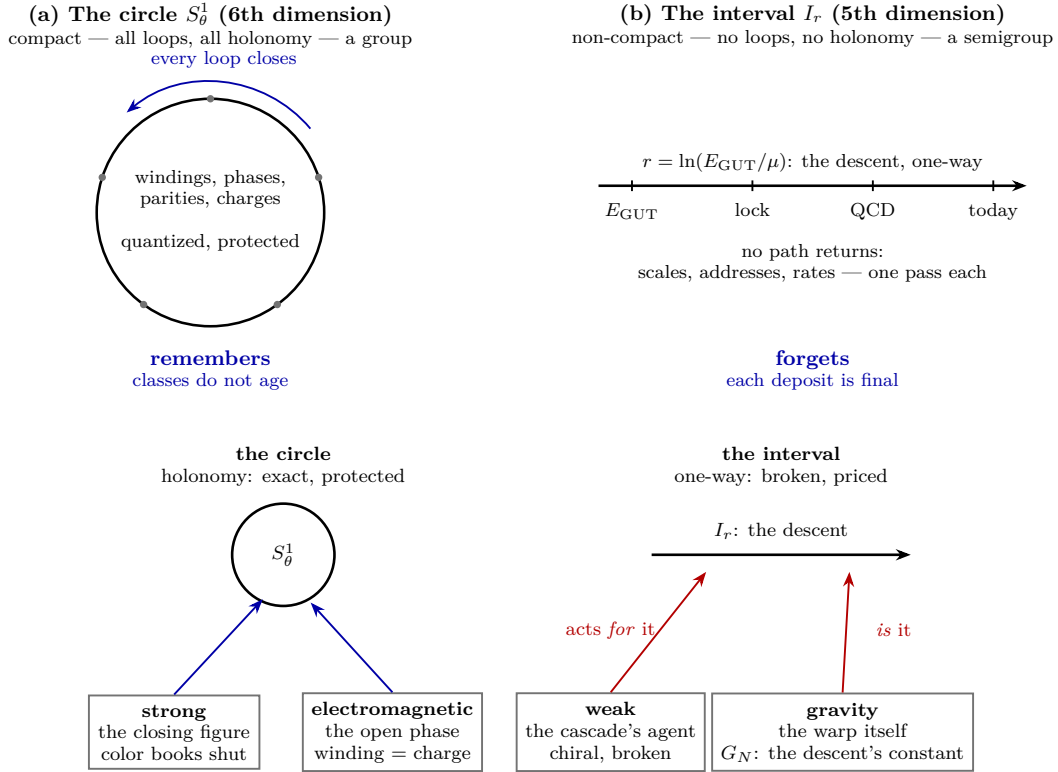
A closing thought. It is worth saying plainly what kind of claim this is. The sentence at the center of this paper — holonomy requires closed loops, and an interval has none — is not a discovery. It is a definition and its first consequence, the sort of thing a graduate student proves in an afternoon. What would be remarkable, if it holds, is not the sentence but its reach: that one such statement, entered into twenty-two independently derived papers through each one’s own central topic, required no value, no grade, and no theorem to change anywhere, and came back out with fifteen dated ways to die.

There is an old suspicion that the effectiveness of mathematics in physics is unreasonable — that the fit between structures invented for their own sake and a world that owes them nothing is a gift we neither earned nor understand (Wigner, 1960). This paper’s answer is not that the puzzle dissolves, but that it may have been posed from the wrong side. If the integers are the topology of the arena rather than a language we brought to it, then mathematics is not being *applied* to the world; it is what the world is made of being read back. That is a strong claim, and it is not yet established — what is established is that a small ledger of integers, fixed by a shape rather than by a fit, reproduces a great deal of what we measure.

The deepest of the sixteen problems are not, in the end, about particles or galaxies. They are about the two things a world has to do at once: be something, and become something. Being requires that some records cannot be destroyed; becoming requires that some steps cannot be undone. Physics has spent a century discovering, one problem at a time, that it needs both and can build neither from the other. The proposal here is that it never had to — that the geometry supplies one of each, and that most of what has looked like a list of separate mysteries is the record of a discipline meeting one shape from sixteen sides. Whether that is true is not for the author to decide. The instruments will settle it, and the paper has said in advance what they should find.

Keywords: six-dimensional bulk; two-fiber anatomy; holonomy; compact fiber and scale interval; group versus semigroup; open quantum systems; measurement and the arrow of time; gauge invariance and renormalization; hierarchy and naturalness; inflation; dark energy; axion dark matter; baryon asymmetry; confinement and proton stability; landscape and multiverse; black-hole information; unsolved problems in physics; GG-Theory

The Circle Remembers; the Interval Forgets — and That One Sentence Sorts All Sixteen



The whole paper in two pictures. Above: the anatomy. Every point of ordinary space carries two further directions, and they are of opposite kind. On the compact circle every path closes, so everything a connection does there is holonomy — quantized, gauge-protected, reversible, a group. On the open interval no path closes, so nothing there can be protected: transport composes forward only, a semigroup, and each step is final. That is the sentence, and it is elementary: *a holonomy requires closed loops, and an interval has none*. Below: the same sentence sorting the four interactions, which is the widest thing it does. Strong and electromagnetic are circle-side, and that is why their charges are exact and unbroken. The weak force is the interval's agent, which is why it alone is chiral, broken and mass-giving. Gravity is not a force on the stage at all but the stage's warp along the descent — why its constant alone is tied to irreversibility, and why it will not quantize like the other three. The century-old puzzle of the four interactions' unlike characters is that sorting, unread. Sixteen open problems are worked the same way in Parts III–VI, none of them newly derived here and each carried at its parent paper's declared grade. In full: Figure 5, p. 48, and Figure 10, p. 73.

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Preface

I have spent fifty years in experimental physics asking one question in many costumes: why is the universe so precisely arranged — for structure, for stability, for us? The GG-Theory cohort is my attempt at a complete answer, developed across some twenty-two research papers; this white paper, the second in the series, is where I step back and show the single newest idea that, to my own surprise, turned out to organize everything else. My first white paper, GG-W1-Symmetry, walked a century of symmetry and conservation and placed the program at the end of that arc. This one is narrower and deeper: it takes the two-fiber anatomy of the six-dimensional bulk — one compact direction that cannot forget, one open direction that cannot remember — and develops it against the sixteen problems I regard as the deepest in particle physics and cosmology.

The idea, in the plainest words I can find. Imagine walking a closed circuit while holding an arrow as steadily as you can. Come back to where you started, and the arrow may have turned. That turning is what geometers call a *holonomy*, and it is the quantity every gauge theory in physics is built from. It needs a loop. In this framework the world has two directions besides the ones you can walk in: one of them closes on itself like a circle, so every path on it is a loop and everything it carries is a holonomy — quantized, protected, and unable to drift. The other is an open stretch with two ends, on which no path closes, so it can hold no holonomy at all and everything on it runs one way and does not come back. The circle remembers. The interval forgets. That is the entire instrument of this paper, and the sixteen problems are what it is pointed at.

Three things I want you to know at the outset. *First*, this paper derives nothing new. Every equation, number, and theorem carried here is proved in a cohort paper, cited at first use and carried at its parent's grade — where a claim is conditional or flagged, the text says so in place, and I ask you to hold me to that. *Second*, the paper is organized as a problem ledger: Part I states the sixteen problems in their own terms, each with its history, its literature, and an honest account of why it has resisted for forty to a hundred years; Part II reviews the program in its four development steps and then builds the anatomy once, equations included; Parts III–VI treat the sixteen, four categories of four, all at essay length or fuller. *Third*, the paper is exposed by design: Part VII collects, in one table, the named measurements on which six of the treatments die outright, and says plainly that the other ten are exposed only through the ledger they share. I would rather be decided than believed.

An invitation, to readers of every kind. I have tried to write this for more than one person at once, and I mean the invitation seriously in each case.

If you are a *curious reader* with no physics training beyond what you have read for pleasure — you are welcome here, and you are not an afterthought. Read the Executive Summary, then the sixteen essays of Part I, which were written to be read the way one reads a good popular science book: history first, then the puzzle, then why it is hard. Then turn to Part X and read the first twenty-two objections, which are the questions people actually ask me: where are the extra dimensions, is this string theory, what about free will, what came before the Big Bang, and — fairly — why should

anyone trust a framework that claims to explain this much. I have answered them plainly, and where the honest answer is “not yet,” I have said so.

If you are a *student* — a senior undergraduate or an incoming graduate — read it straight through. It assumes first-year graduate physics and nothing at all about this program. Part IX is for you in particular: nine topics, each taken in four steps, beginning with a full textbook treatment of the standard material before a word is said about anything new, with derivations written out and problems worked. If you learn the standard physics from those pages and decide the rest is wrong, the appendix will still have done its job.

If you are a *specialist* in one of these sixteen areas, you will know more about your own problem than this paper does, and that is as it should be — it is a synthesis, and its claim is about the pattern rather than about any single entry. The fastest honest route is Part II, then the section on your problem, then the honest ledger (§47) and the ways to be wrong (§48). If the treatment of your problem is wrong, it will be wrong in a checkable way, and I would be glad to be told.

If you are a *skeptic* — and I hope some of you are, because a framework of this scope deserves hard readers — start at Part X. I have not hidden the objections at the back to be polite about them; they are stated in their sharpest form, several of them are conceded outright, and the master table grades every one of the sixteen with a deliberately varied verb, because *solved* is not what most of them earned.

A last word. Physics is not a private activity, and no framework of this size is ever finished by the person who proposed it. Whatever survives of this one will survive because other people checked it, and what does not survive will fall for the same reason. That is not a disappointing thought; it is the only arrangement under which any of this means anything. If a single reader closes this paper with a clearer picture of what the sixteen problems actually are — even one who is certain the answer offered here is wrong — then the writing was worth the years.

Part I

Introduction

Sixteen Unsolved Problems in Particle Physics and Cosmology, and One Sentence

1 The sixteen problems

Every era of physics keeps a short list of questions its own tools cannot close. What is unusual about the present list is how little it has moved. Four decades of colliders, telescopes, and theory programs have sharpened every entry on it and closed almost none; most entries predate the career of anyone now working, and several predate the careers of their teachers. The measurement problem was posed in the 1920s. Dark matter was inferred in 1933. The strong- CP problem and the black-hole information paradox both date from 1976, the hierarchy problem from 1979, and the cosmological constant problem was already a scandal when the acceleration was discovered in 1998.

A list that stable is itself a piece of evidence, and it can be read two ways. Either these are simply hard problems, unrelated to one another, each awaiting its own breakthrough — the reading under which the discipline has worked for two generations. Or the list is long because one structural fact about the world is missing from all of them at once, and each entry is that absence, seen from a different direction. This paper takes sixteen of the deepest problems — grouped into four categories of four — and develops the second reading: *a single structural sentence about the six-dimensional bulk addresses all sixteen*. The sentence is built in Part II. The problems, and where each is treated, are these:

Table 1: The sixteen problems, their categories, and the anatomy’s answer in one line. All sixteen are developed at essay length; the seven rows marked • additionally carry the fullest quantitative apparatus — figures, tables, and complete chains. The numbering established here is the paper’s primary cross-reference: every later Part cites its subject as Problem n rather than by name.

#	Problem	The anatomy’s answer, in one line
<i>Part III — The Standard Model</i>		
1	Measurement problem of quantum mechanics	coherence is the circle’s; registration is an interval-side write — a measurement is a read
2 •	Strong, weak, EM, and gravity: why so different	two keepers on the circle, one agent on the interval, one integrator
3	Origin of local gauge invariance and renormalization	gauge symmetry is the circle’s unreadability; renormalization is motion along the interval
4	Too many free parameters (SM and Λ CDM)	every parameter is a holonomy label wearing a descent address — a codebook, not a fit
<i>Part IV — Cosmology</i>		
5	The beginning of the universe	“what banged?” becomes “what launched the descent?” — and the launch is derived
6	Naturalness and the hierarchy problem	nothing is small; something is deep — e^{-K} , counted, not tuned
7 •	The dark trio: inflation, dark energy, dark matter	the interval’s coordinate rolling, the circle’s ringing, and both at rest
8	The three horizon problems	same temperature by the launch; same particles by the classes; same laws by the groove
<i>Part V — Foundation of Particle Physics</i>		
9 •	Discrete symmetry: C , P , T , CP , CPT (+ strong CP)	orientation choices of the geometry; fates assigned by fiber
10 •	Origin of antiparticles	the same circle-side class, read in the mirror orientation
11 •	The tiny excess of matter (baryogenesis)	a chiral tape, read once, through a gated door, at a toll of $e^{-K/2}$
12 •	Quark confinement; absolutely stable protons	the triangle that closes; the gauged ledger with no aperture
<i>Part VI — Foundation of the Cosmos</i>		
13 •	Definition of time and the arrow of time	the circle gives the tick; the interval gives the direction
14	Definition of energy, mass, and entropy	what the tick is worth; an address a class wears; what the arrow has read
15	Landscape and multiverse problems	a dial, not a hat: one groove, one playback — the multiverse is unemployed
16	Black-hole information paradox	a billing error: the circle keeps what the hole must return; the interval prices the return

Three features of the table are the paper’s thesis in miniature. *First*, the right column is one vocabulary: every answer is a sentence about a compact circle that remembers and an open interval

that forgets. *Second*, the sixteen problems span every register of the discipline — foundations, phenomenology, cosmology, and interpretation — and the standard literature treats them in at least six disjoint languages; whatever else is true of the anatomy, its *reach* is a fact on display in this table. *Third*, the table is falsifiable row by row: Part VII consolidates the named measurements on which the entries die.

2 How to read the sixteen

The rest of this Part walks the sixteen, one at a time, at about half a page each. The purpose of the walk is not to answer anything — the answers are Parts III–VI — but to establish two things a reader is entitled to demand before being asked to accept a new structural idea.

The first is that these problems are real, and are not the private obsessions of one program. Each entry below is stated as its own literature states it, with the history that produced it and the names attached: the people who posed each question were among the most capable in the discipline, and the strategies that failed on it failed for interesting reasons, not foolish ones. Where a rival research program has a genuine achievement — and several have large ones — the achievement is stated before the shortfall.

The second is the diagnosis. Each entry ends with the same uncomfortable question: *why has this resisted for forty, seventy, a hundred years?* The answers turn out to rhyme, and the rhyme is the motivation for everything that follows. It is developed in §7 once all sixteen are on the table. The reader should know that this is not a survey of curiosities. Two of the sixteen have already had a candidate answer removed by experiment in the last six years — the strong- CP angle’s window narrowed again (Abel et al., 2020), and the possibility that quantum mechanics could be built on real numbers alone shown falsifiable (Renou et al., 2021) and then excluded by network Bell tests (Li et al., 2022; Chen et al., 2022) — and a third, the Hubble tension, has hardened from an anomaly into a structural question about which clock cosmology is reading (Arisaka, 2026, C2-Hubble). These are live problems, moving under instruments now running.

3 Category I — The Standard Model: the theory that works too well

The Standard Model is the most precisely tested theory in the history of science, agreeing with experiment in some quantities to twelve significant figures. Its four unsolved problems are therefore of a peculiar kind. None of them is a discrepancy. All four are questions about *why the theory has the shape it has* — and the theory, by construction, cannot be asked.

3.1 Problem 1. What happens when a measurement happens

Quantum mechanics contains two rules for how states change, and no rule for when to use which. Between measurements a state evolves smoothly, reversibly, and deterministically, by the Schrödinger equation. At a measurement it does something else entirely: it jumps to one outcome, irreversibly, with a probability given by the squared amplitude — the rule Born (1926) added to his paper in

proof, in a footnote, which is now the most successful statistical prediction in physics. The two rules contradict each other, and the theory says nothing about the border between them. [von Neumann \(1932\)](#) made this explicit, distinguishing the unitary “process 2” from the collapse “process 1” and observing that the cut between them can be slid anywhere between the atom and the observer’s eye without changing any prediction — a movable seam is not a physical boundary, and he knew it. The problem then hardened rather than resolved. [Einstein et al. \(1935\)](#) argued from locality that the quantum description must be incomplete — a dilemma the century has since read the other way round: keep completeness, and locality is what gives; Schrödinger’s cat, from the same year, showed that the ambiguity can be amplified to household scale. Thirty years later [Bell \(1964\)](#) converted the metaphysics into an inequality, and the experiments that followed closed the local hidden-variable escape for good. Meanwhile the interpretations multiplied: [Everett \(1957\)](#) removed the collapse by keeping every branch; [Ghirardi et al. \(1986\)](#) modified the dynamics so that collapse is a physical process with its own rate; and the decoherence program ([Zurek, 2003](#)) showed in detail how interference disappears when a system is coupled to an environment.

Why has this survived a hundred years? Because each strategy pays for its solution in a currency the others will not accept, and no experiment adjudicates. Everett keeps the mathematics intact and owes an account of why the Born weights are the probabilities of anything at all. Dynamical collapse buys single outcomes with new constants and a hard fight with relativity. Decoherence, the most successful of the three, explains why the interference is unobservable but takes as given the very things it was asked to explain — which variables are the classical ones, and why the squared amplitude sets the odds — and it never produces a single outcome, only an ensemble that looks like one. A century on, the options remain empirically indistinguishable by construction. That is the shape of the problem: not undertested, but posed in a frame where testing cannot help. *Treated as Problem 1 in Part III.*

3.2 Problem 2. Why the four interactions are so unlike

Nature runs on four interactions, and their family resemblance is poor. Electromagnetism is exact, unbroken, infinite in range, and carried by a massless quantum. The strong interaction is so powerful that its charges are never seen alone. The weak interaction is short-ranged and feeble, and is the only one that distinguishes left from right, the only one that changes what a particle is, and the only one that violates CP . Gravity is not like any of them: it couples to everything, cannot be switched off, has a dimensionful constant, and has resisted seventy years of attempts to quantize it in the manner that worked for the other three.

The historical arc is one of triumphant unification that stops short of explanation. [Fermi \(1934\)](#) wrote the weak interaction as a contact term. [Yang and Mills \(1954\)](#) generalized the gauge principle to non-abelian groups, giving all of the non-gravitational forces their common language. Electromagnetism and the weak force were then unified ([Weinberg, 1967](#)) and confirmed spectacularly, and the discovery of asymptotic freedom ([Gross and Wilczek, 1973](#); [Politzer, 1973](#)) completed the strong sector. [Georgi and Glashow \(1974\)](#) took the natural next step and embedded all three in a single group — a beautiful proposal whose simplest version predicted proton decay at a rate that experiment has now excluded.

So why, after seventy years, is the difference between the forces still unexplained? Because the successful strategy was *embedding*, and embedding explains sameness, not difference. Grand unification makes the three forces alike at high energy and relegates their present unlikeness to the accident of a symmetry breaking pattern chosen to fit. Within the Standard Model itself, the differences are inputs, not outputs: the gauge group is written as a product of three factors by hand; the chirality of the weak force is assigned by hand; and the three coupling strengths are measured, not derived. Gravity's exclusion is worse than an accident — it is structural, and the very feature that resists quantization, its dimensionful constant, is a clue that it is not the same kind of object as the other three. *Treated as Problem 2 in Part III.*

3.3 Problem 3. Where gauge invariance and renormalization come from

Two principles carry the entire predictive weight of modern field theory, and neither is explained by the theory that uses them.

The first is local gauge invariance. [Weyl \(1929\)](#), after an earlier failed attempt to gauge the scale of length, found that demanding invariance under a position-dependent phase forces the existence of the electromagnetic field and fixes how it couples. The trick is so powerful that it became the standard way to invent new physics. But its status is strange. [Noether \(1918\)](#) had already proved, in the second theorem of the same paper that gave physics its conservation laws, that a symmetry holding independently at every point yields no conserved quantity — only an identity. [Elitzur \(1975\)](#) sharpened the discomfort: a local gauge symmetry can never break, because it is not a symmetry of states at all, but a redundancy in our labeling of them. A redundancy in a description is not the kind of thing that ought to dictate the forces of nature. Yet it does.

The second is renormalization. It began as an embarrassment — infinities subtracted by hand to save quantum electrodynamics ([Dyson, 1949](#)) — and became a triumph when the procedure was shown to work for non-abelian theories (['t Hooft and Veltman, 1972](#)) and then reinterpreted by [Wilson and Kogut \(1974\)](#) as a flow: couplings are not constants but functions of the scale at which one looks, and the flow runs one way, from fine resolution to coarse.

Why is this still open? Because both principles are described perfectly and explained not at all. Nobody can say what the gauge circle *is* without speaking gauge language: the standard answer, that it is a redundancy, makes its dictatorial power over the dynamics more mysterious, not less. And renormalization's most important feature is the one least accounted for — its irreversibility. The flow's arrow, the special status of the scale variable, and the fact that only a handful of operators survive the descent are all facts about a direction, in a framework whose other directions are ordinary spacetime. A century after Weyl, the two principles remain the tools we cannot do without and cannot derive. *Treated as Problem 3 in Part III.*

3.4 Problem 4. Too many numbers that nobody can compute

The Standard Model has never been a theory of everything it describes. Roughly two dozen numbers — three gauge couplings, nine charged-fermion masses, four mixing angles and phases, the Higgs mass and vacuum value, plus the neutrino sector's masses and mixings, and the QCD vacuum angle — must be measured and inserted by hand ([Particle Data Group, 2024](#)). Cosmology adds six more

for Λ CDM. [Cahn \(1996\)](#) put the discomfort well by tracing what everyday life would look like if each were slightly different: these are not bookkeeping conventions but the numbers that decide whether atoms, chemistry, and stars exist.

The history is a sequence of serious attempts to reduce the count, each of which increased it. Grand unification related the three gauge couplings at one scale — a real success, at the price of new scales and a proton lifetime now excluded in the simplest models. Supersymmetry stabilized the Higgs mass and, in its minimal realization, introduced more than a hundred additional parameters. Technicolor, extra dimensions, and flavor textures each traded a handful of numbers for a mechanism carrying its own. The string landscape offered, in place of a computation, an astronomical number of consistent vacua and a selection principle (Problem 15).

Why has this resisted for fifty years? Because of a fact about the architecture, not about anyone's ingenuity: quantum field theory is a *framework*, and in a framework the parameters are inputs. Any values are internally consistent; nothing in the mathematics prefers $\alpha^{-1} = 137.036$ to any other number. A theory whose own structure cannot distinguish the true values from false ones cannot compute them, no matter how long it is studied — and every attempt to embed it in a larger structure has so far added more freedom than it removed. The count has gone up, not down, in half a century of trying. *Treated as Problem 4 in Part III.*

4 Category II — Cosmology: the universe that had to begin

Cosmology's four problems have the opposite character to the Standard Model's. There the theory is too good and cannot be questioned; here the theory is a magnificent fit with almost no explanation underneath it. Six numbers reproduce the whole observed universe — and all six are measured, none derived.

4.1 Problem 5. What happened at the beginning

Every other question in physics can be asked about a system with a past. This one cannot, and that is what makes it different in kind. [Lemaître \(1931\)](#) first proposed that the expansion runs back to a beginning, and general relativity was later shown to insist on it: under conditions that hold in our universe, the equations force a singularity, a moment where the description ends rather than continues ([Hawking and Penrose, 1970](#)). Since a singularity is a failure of the theory, not an event within it, the beginning became the one place where physics had to concede that it did not apply. Inflation transformed the question without answering it. [Guth \(1981\)](#), followed by [Linde \(1982\)](#) and building on [Starobinsky \(1980\)](#), showed that a brief early episode of accelerated expansion would explain the sky's uniformity, its flatness, and — the triumph — the precise spectrum of tiny density ripples that later became galaxies. Those predictions have been confirmed to remarkable precision ([Planck Collaboration, 2020](#)). But inflation is a mechanism, not an origin: it requires a field with a suitable potential, placed in a suitable initial state, over a region large enough to inflate. [Borde et al. \(2003\)](#) proved that inflation cannot be eternal into the past, so the question survives its own solution.

Underneath sits a sharper puzzle that inflation does not touch. [Penrose \(1979\)](#) pointed out that the

early universe was not merely hot and dense but *extraordinarily special*: its gravitational degrees of freedom were almost entirely unexcited, a condition of staggeringly low probability on any natural counting, and the only reason the second law has anywhere to run.

Why has this resisted for a century? Because the standard framework splits every explanation into two parts — a law and an initial condition — and awards itself only the first. Initial conditions are, by the framework’s own rules, inputs: chosen, not computed. That works everywhere except at the one place where there is no earlier state to choose them from. So the beginning is not merely unknown, it is *structurally unaskable* in the language used to describe everything after it. *Treated as Problem 5 in Part IV.*

4.2 Problem 6. Why the scales are so absurdly far apart

The weak scale sits about seventeen orders of magnitude below the Planck scale, and the energy density of the vacuum sits some one hundred and twenty orders below its naive estimate. These two numbers are the most spectacular unexplained ratios in science.

The anxiety has a long pedigree. Dirac (1937) noticed that several enormous dimensionless ratios in nature cluster near 10^{40} and its powers, and concluded — wrongly, but fruitfully — that such numbers must be dynamical. The modern form arrived with Susskind (1979), who observed that quantum corrections drag a scalar’s mass toward the highest scale in the theory, so the Higgs mass appears to require a cancellation of extraordinary precision. ’t Hooft (1980) gave the doctrine its respectable form: a small number is acceptable if setting it to zero enlarges the symmetry. On that criterion the Higgs mass is unnatural, and an entire generation of model building — most of it supersymmetric — was launched to protect it. The vacuum energy is worse still: Weinberg (1989) reviewed the problem before dark energy was observed, and the measured value (Riess et al., 1998; Perlmutter et al., 1999) sits far below every estimate the framework can produce.

Why has this resisted for forty years? Because naturalness is a statement about *probability across a space of theories*, and no such probability measure exists. The doctrine told a generation where to look; the Large Hadron Collider then found the Higgs inside the light-mass window the electroweak fits favored — and nothing else at the scale naturalness demanded. The community is left with a criterion that was enormously productive, is not a law, cannot be checked, and has now returned its clearest experimental verdict — a null. Meanwhile the framework’s own logic guarantees that any small parameter it does not protect by symmetry will be dragged large, so the hierarchy cannot be explained from inside; it can only be assumed, protected, or selected. *Treated as Problem 6 in Part IV.*

4.3 Problem 7. What most of the universe is made of

Ordinary matter — everything ever detected in a laboratory — accounts for about five percent of the universe. About twenty-seven percent is a form of matter that clusters gravitationally and does nothing else visible, and the remaining sixty-eight percent is something with negative pressure that is pushing the expansion apart.

Zwicky (1933) noticed the first: galaxies in the Coma cluster were moving far too fast for the visible mass to hold them. Rubin and Ford (1970) measured Andromeda’s rotation curve out to

large radius, and the spiral surveys that followed made the case inescapable; the evidence has since become overdetermined — lensing, the cosmic microwave background, the growth of structure. The leading candidate for decades was a heavy weakly-interacting particle; a second, arising elsewhere entirely, was the axion, invented to solve a different problem (Peccei and Quinn, 1977; Weinberg, 1978; Wilczek, 1978) and then recognized as a natural relic (Preskill, Wise, and Wilczek, 1983). Dark energy arrived abruptly with the supernova measurements (Riess et al., 1998; Perlmutter et al., 1999), and everything since is consistent with a constant.

Why has this resisted for ninety years? For dark matter, because the evidence is entirely gravitational and therefore says almost nothing about what the particle *is*: the allowed mass range spans some ninety orders of magnitude, and the theory offers no principle to prefer a point in it. Two generations of increasingly sensitive detectors have returned nulls, which excludes parameter space without indicating where to look next. For dark energy, the difficulty is sharper: its value is not merely unexplained but anti-explained, since the framework’s own estimate is wrong by a factor no mechanism has produced. And the coincidence that the two components have comparable densities *now*, after billions of years of very different scaling, is a puzzle nobody has been able to convert into a prediction. *Treated as Problem 7 in Part IV.*

4.4 Problem 8. Why distant strangers agree

Look at two patches of sky in opposite directions. Their light has been traveling toward us for the age of the universe, so on any straightforward accounting they have never exchanged a signal — nothing that happened in one could have influenced the other. Yet they have the same temperature to one part in a hundred thousand, contain the same kinds of particles with identical properties, and obey the same laws with the same constants.

Misner (1968) first pressed the first of these agreements as a crisis — the horizon problem — and inflation was designed largely to solve it: if the observed sky descends from one tiny causally connected patch that was then stretched enormously, the uniformity is inherited rather than coincidental (Guth, 1981). This is one of the genuine explanatory successes of twentieth-century cosmology, and this paper does not dispute it.

But it buys only the first agreement. Inflation explains why remote regions began at the same temperature; it does not explain why the electron in a quasar twelve billion light-years away has precisely the mass of the electron in this room, nor why the fine-structure constant is the same there as here, nor why regions that made their own choices about which vacuum to settle into — the electroweak vacuum, the QCD vacuum angle, the axion misalignment — made the *same* choices, when the standard picture of symmetry breaking is a random fall from a symmetric hilltop, chosen independently in each causally disconnected patch. On the textbook account the sky should be a patchwork of domains separated by walls. It is not, to the precision of every measurement made. Why has this resisted? Because the mechanism that answers the first agreement is causal — stretch, so everything shares a past — and the second and third agreements are about *choices made after the stretch*, which a shared past cannot reach. The literature has largely not treated them as one problem, and the escape usually offered, that constants are simply constants, restates the assumption rather than explaining it. *Treated as Problem 8 in Part IV.*

5 Category III — The foundation of particle physics: how matter got here

The third group asks how the universe came to contain stable matter at all — which turns on three discrete symmetries, one missing antiworld, and one interaction that refuses to let its charges out.

5.1 Problem 9. Why the mirrors break, and one does not

Three discrete operations were long assumed to be exact symmetries of nature: reflection in a mirror (P), exchange of particles with antiparticles (C), and reversal of the direction of time (T). None of the three survives intact — T violation has now been seen directly as well (Lees et al., 2012) — and only the product CPT has never failed. That pattern of failure is the deepest unexplained regularity in particle physics.

Lee and Yang (1956) pointed out that parity had never actually been tested in weak decays; within months Wu et al. (1957) found it maximally violated. Combined CP was expected to survive — and then Christenson et al. (1964) found it broken too, at the level of two parts in a thousand, in the decays of neutral kaons. Kobayashi and Maskawa (1973) showed that a third generation of quarks would allow exactly one such phase in the Standard Model, a prediction brilliantly confirmed. Only CPT has never been seen to fail; it is protected by a theorem (Lüders, 1954) resting on locality, Lorentz invariance, and positive energy.

Alongside sits a puzzle of the opposite kind. Quantum chromodynamics *permits* a CP -violating term, with an angle that could take any value between zero and 2π ('t Hooft, 1976). Measurements of the neutron's electric dipole moment show it is smaller than about 10^{-10} (Abel et al., 2020) — a number consistent with zero, and consistent with nothing else. Peccei and Quinn (1977) proposed a new symmetry to relax it dynamically, whose leftover particle is the axion.

Why has this resisted for seventy years? Because the Standard Model *accommodates* the pattern without producing it. Parity violation is written in by assigning left- and right-handed particles to different representations; CP violation is written in as a phase whose size is measured; the strong- CP angle is written in as a free number that experiment then says is zero. Each fact is an input chosen to match the world. And CPT 's exactness, though proved, is proved from assumptions rather than explained — the theorem tells us the three operations are linked, not why the geometry offers exactly three. *Treated as Problem 9 in Part V.*

5.2 Problems 10–11. Where antimatter came from, and where it went

Antimatter was a mathematical accident before it was a discovery. Dirac (1928) found that making the electron's equation compatible with relativity forced negative-energy solutions, and after three years of embarrassment — during which he first tried to identify the extra solutions with protons — he read them, in 1931, as a new particle of opposite charge and identical mass (Dirac, 1931). Anderson (1933) then photographed one. Every charged particle found since has a partner, with mass and lifetime equal to fantastic precision and every charge reversed.

That precision is itself the first question. Nothing in the framework explains why the mirror is *exact*

in mass and *perfect* in charge reversal; antimatter is written into the formalism as a second set of field components, and its properties are consequences of a construction chosen because it works. The second question is why there is anything left. Matter and antimatter annihilate; a universe that began with equal amounts would now contain radiation and almost nothing else. Instead there are about six surplus baryons for every ten billion photons. [Sakharov \(1967\)](#) laid down the three conditions any explanation must satisfy: baryon number violation, C and CP violation, and departure from thermal equilibrium. The Standard Model formally contains all three — CP violation from the quark phase, baryon number violation through non-perturbative processes ([Kuzmin et al., 1985](#)) — and yet fails quantitatively by a catastrophic margin: the quark phase delivers an asymmetry at least ten orders of magnitude too small ([Gavela et al., 1994](#)). The most successful alternative moves the origin to the neutrino sector ([Fukugita and Yanagida, 1986](#)), where heavy right-handed neutrinos decay out of equilibrium and the resulting lepton asymmetry is converted to baryons.

Why has this resisted for sixty years? Because leptogenesis, the leading mechanism, does its work at energies and with masses that no experiment can reach: the framework is right, and the numbers inside it are free. Any observed asymmetry can be accommodated by choosing the heavy masses and phases appropriately, which means the observed value has never been *predicted* — only fitted. *Treated as Problems 10–11 in Part V.*

5.3 Problem 12. Why quarks are never seen, and why the proton lives forever

Two of the most basic facts about matter are, in the strict sense, unproven.

The first is confinement. [Gell-Mann \(1964\)](#), and independently Zweig, proposed quarks as constituents while stressing that none had ever been observed; [Greenberg \(1964\)](#) added the three-valued degree of freedom that became color and made the arithmetic work. Half a century of searches has found no free quark and no free color charge, and lattice computations show the confining behavior convincingly — but a proof, from the theory’s own equations, that color charges cannot be isolated does not exist; the closely related problem of constructing quantum Yang–Mills theory and proving it has a mass gap is one of the Clay Millennium Prize problems ([Jaffe and Witten, 2006](#)), unclaimed. The qualitative mechanism is understood as a flow along the scale variable ([Wilson, 1974](#)) in which the coupling grows toward low energy until the perturbative description fails — an argument that says the calculation breaks down, not that the charges are imprisoned.

The second is proton stability. Nothing in the Standard Model’s structure *forbids* the proton from decaying; baryon number is an accidental symmetry, a bookkeeping regularity that happens to hold for the operators one can write at low energy, and grand unification predicted that it should fail. Experiment says otherwise, with a lower bound on the lifetime now beyond 10^{34} years ([Takenaka et al., 2020](#)) — more than twenty orders of magnitude longer than the age of the universe.

Why has this resisted for sixty years? Because the two facts pull in opposite directions. Confinement resists proof because the interesting regime is precisely where the tools fail; the successful description is a numerical simulation, which demonstrates rather than explains. Proton stability resists explanation because the framework offers it as an accident, and accidents of that precision — a bound thirty-four orders of magnitude out — are exactly what theories are supposed to explain.

That every atom in the universe depends on this accident holding is the sharpest way to state the discomfort. *Treated as Problem 12 in Part V.*

6 Category IV — The foundation of the cosmos: the words we never defined

The last four are the least discussed and the most fundamental. Two of them concern words physics uses on every page without defining; the other two concern the limits of explanation itself.

6.1 Problem 13. What time is, and why it only runs one way

Physics measures time to seventeen decimal places and does not say what it is measuring. The fundamental equations make the omission conspicuous, because almost all of them work equally well in both directions. Newton’s laws, Maxwell’s equations, general relativity, and the Schrödinger equation are all reversible: run any solution backwards and you get another solution. Yet nothing in experience is reversible. Boltzmann (1877) located the asymmetry in counting — there are overwhelmingly more disordered configurations than ordered ones — and Eddington (1928) gave the second law its famous status as the one law of nature whose violation would leave no defense. But counting alone cannot produce an arrow: the same argument, run backwards, predicts that entropy was higher in the past too, which is false. The missing ingredient is the extraordinarily low-entropy initial condition (Penrose, 1979), which pushes the arrow of time back into Problem 5. Quantum gravity makes the situation stranger still. The Wheeler–DeWitt equation (DeWitt, 1967), the canonical quantization of general relativity, contains no time variable at all: the universe’s wavefunction simply does not evolve. Whether this is a technical artifact or the deepest fact about time has been argued for sixty years without resolution.

Why has this resisted for a century? Because time enters every framework as a *parameter*, supplied from outside, never derived. The theories describe change with respect to t and never say what t is; the arrow is then imported from an initial condition that the same theories decline to explain; and the one place where time might have been derived — the quantization of gravity — responds by making it vanish. *Treated as Problem 13 in Part VI.*

6.2 Problem 14. What energy, mass, and entropy actually are

The three most-used quantities in physics have no definitions — only recipes for computing them. Feynman et al. (1963) put it bluntly in his introductory lectures: physics knows that a certain quantity is conserved, and does not know what that quantity *is*. Energy is defined as the conserved charge of time-translation symmetry (Noether, 1918), which is mathematically exact and explanatorily circular if one is also asking what time is (Problem 13). Mass is a parameter in a Lagrangian, or a coefficient in a dispersion relation, or — since Einstein — a form of energy, without any statement of what distinguishes the kind of energy that has mass from the kind that does not.

Entropy is worse, because it has several inequivalent definitions in daily use — Clausius’s heat over temperature, Boltzmann’s count of microstates, Gibbs’s ensemble average, Shannon’s information

measure, von Neumann’s quantum version, and, most strangely, Bekenstein’s area of a black-hole horizon (Bekenstein, 1973), which says that an entropy can be a *geometrical* quantity. Landauer (1961) then showed that information and thermodynamics are not analogies but the same ledger: erasing one bit necessarily dissipates a definite minimum of energy.

Why has this resisted? Because in each case the framework provides a *procedure* where an account was wanted, and the procedures work so well that the absence is easy to overlook. The three quantities are also mutually entangled: energy is defined by time, entropy by the arrow of time, mass by energy. Nothing in the standard framework offers an independent structure from which all three could be read — and the one hint that such a structure exists, the appearance of an entropy as an area, has been tantalizing physicists for fifty years. *Treated as Problem 14 in Part VI.*

6.3 Problem 15. Whether the constants were selected rather than explained

By the late 1990s, two developments had converged on a radical proposal: perhaps the constants of nature cannot be computed at all, because they are not universal.

The first was Weinberg (1987), who argued before the discovery of dark energy that if the vacuum energy varied across regions, only regions where it is small enough for galaxies to form could contain observers — and derived, on that basis, an anthropic upper bound some two orders of magnitude above the value later measured. A bound is not yet a prediction; sharpening it into one needed a measure, which is where the difficulty begins. The second was the discovery that string theory appears to admit an astronomical number of consistent vacua (Bousso and Polchinski, 2000), each with different effective constants, and the proposal to take that landscape seriously as a physical ensemble (Susskind, 2003). If eternal inflation populates the vacua, the constants become environmental — like the distance from the Earth to the Sun, not a number to be derived but a place where observers happen to find themselves.

This is a coherent and honest position, and its bound remains the tradition’s most impressive single result. But it carries a bill that has never been paid. To make a prediction from an ensemble one needs a probability measure over it, and in an infinite, eternally inflating multiverse every proposed measure gives different answers, with no principle selecting one — the measure problem. And the framework is difficult to expose: a theory predicting that everything possible occurs somewhere is not easily proved wrong.

Why has this resisted — thirty-nine years since the anthropic bound, twenty-six since the landscape? Because it is not really a physics problem but a fork in what counts as an explanation. One branch says constants are contingent and the search for derivations is a category error; the other says they are computable and nobody has computed them. The dispute cannot be settled by argument — only by somebody actually deriving the numbers, or by the landscape delivering a measure. *Treated as Problem 15 in Part VI.*

6.4 Problem 16. What a black hole does with what it swallows

Bekenstein (1973) argued that a black hole must carry an entropy proportional to the area of its horizon, and Hawking (1975) then proved that it radiates like a hot body. Together these results were a triumph — and immediately a catastrophe. If the radiation is exactly thermal, it carries no

information about what fell in, so when the hole finishes evaporating the information is gone, and quantum mechanics’ foundational rule that evolution is reversible has failed (Hawking, 1976).

Fifty years of attempts have produced deep physics and no consensus. Black-hole complementarity proposed that no single observer ever sees a contradiction (Susskind et al., 1993). The gauge/gravity duality (Maldacena, 1998) gave strong indirect evidence that gravitational evolution is unitary, without identifying the mechanism. Page (1993) showed what the schedule must look like if information does come out: the radiation’s entanglement entropy must rise, turn over at about half the evaporation, and fall back to zero. Then Almheiri et al. (2013) sharpened the paradox into a trilemma — unitarity, locality, and a smooth horizon cannot all survive — suggesting a “firewall” at the horizon. Most recently, calculations of entanglement islands (Penington, 2020) recovered the Page curve from gravity itself.

Why has this resisted for fifty years? Because the paradox sits precisely where the two great theories of the twentieth century overlap and disagree, and there is no experiment: Hawking radiation from an astrophysical black hole is unobservably faint, and the process under dispute takes longer than the age of the universe. The recent island computations are a genuine advance — they get the right curve — but they compute *that* the books balance rather than saying *where* the information was held while the hole existed. *Treated as Problem 16 in Part VI.*

7 What the sixteen have in common

Sixteen problems have now been stated in their own terms. Set side by side, three patterns are hard to miss.

7.1 They are old, and they have not been getting younger

Table 2 dates each problem to the year it took its modern form. The median entry is seventy years old. Twelve of the fifteen dated entries are older than half a century, six are older than ninety years, and the youngest — the landscape — is thirty-nine. In the same period the discipline built the Standard Model, discovered the W , Z , top quark and Higgs, measured the microwave background to cosmic-variance limits, detected gravitational waves and neutrino oscillations, and confirmed inflation’s spectral predictions. It was not a period of weakness. The list survived it anyway.

Table 2: The sixteen problems, dated to the year each took its modern form, with age in 2026. Median age: seventy years. Twelve of the fifteen dated entries predate 1976. The oldest is Problem 14, Noether’s 1918 statement of the energy question, at a hundred and eight; the youngest is the landscape, at thirty-nine. Problems 10 and 11 share a row and a date, Sakharov’s 1967.

#	Problem	Posed	Age
1	The measurement problem (Schrödinger’s cat)	1935	91
2	Why the interactions differ (Yang–Mills)	1954	72
3	Gauge invariance and renormalization (Weyl)	1929	97
4	Too many free parameters	1975	51
5	The beginning of the universe (Lemaître)	1931	95
6	Naturalness and the hierarchy	1979	47
7	The dark sector (Zwicky)	1933	93
8	The horizon problems (Misner)	1968	58
9	Discrete symmetry (Lee–Yang)	1956	70
10–11	Antimatter and the excess (Sakharov)	1967	59
12	Confinement and the stable proton	1964	62
13	The definition and arrow of time (Eddington)	1928	98
14	Energy, mass, entropy (Noether)	1918	108
15	The landscape and the multiverse	1987	39
16	Black-hole information (Hawking)	1976	50

When a research program fails for a decade, the natural explanation is that the problem is hard. When sixteen independent programs, run by the ablest people in the field with the best instruments ever built, all fail for half a century or more, a second explanation deserves a hearing: that they share an obstruction, and that the obstruction is upstream of all of them.

7.2 They are all the same kind of question — and it is the kind the framework cannot take

Read the sixteen again and notice what none of them is. Not one is a discrepancy. Not one says the equations gave the wrong number. Every single one asks *why the structure is what it is*: why two dynamics, why four forces, why these constants, why this beginning, why this arrow, why exactly these three discrete operations, why the books balance.

Quantum field theory and general relativity are magnificent machines for a different question. Given a structure — a manifold, a gauge group, a field content, a set of couplings, an initial state — they compute what happens next, superbly. But the structure is the *input*. A framework that takes structure in cannot hand structure out, and no amount of skill inside it will change that. This is why each of the sixteen ends the same way: the literature answers it by choosing something. The gauge group is chosen. The chirality assignment is chosen. The parameters are measured and inserted. The initial condition is stipulated. The placement of the quantum-classical cut is left to convenience. The proton’s stability is called an accident. The constants are called environmental. Each move is respectable, and none is a computation.

7.3 They sort into two families, and the sorting is the clue

The third pattern is the one this paper is about. Sort the sixteen by what they are really asking, and they fall into two families with almost no overlap.

One family is about things that never change. *CPT* holds exactly. Electric charge is quantized exactly. The proton does not decay. An antiparticle's mass matches its partner's to every measured digit. The electron in a distant quasar is identical to the one in this room. Anomaly coefficients are integers and do not run. Color charges are never seen alone. These are questions about *protection*: what could possibly make a quantity so exact that fifty years of increasingly sensitive experiments cannot budge it?

The other family is about things that only go one way. A measurement, once registered, cannot be unregistered. The renormalization flow runs from fine to coarse and not back. Entropy increases. The universe descends from hot to cold, once. A black hole evaporates. Time has a direction. These are questions about *irreversibility*: what could possibly make a direction in which nothing returns, in a world whose fundamental equations are reversible?

Now the difficulty comes into focus. Physics has exactly one language for both families: fields living on a four-dimensional spacetime. In that language every direction is the same kind of direction — you may traverse it either way — so nothing in the geometry is intrinsically protective and nothing is intrinsically one-way. Both properties must therefore be imported: exactness as an assumed symmetry or a fortunate accident, irreversibility as a special initial condition or a coarse-graining we chose to perform. And because both are imported into the same undifferentiated arena, the two families keep contaminating each other. The measurement problem is the collision of a reversible law with an irreversible record. The strong-*CP* problem is an exact quantity that the framework says should be arbitrary. The arrow of time is irreversibility demanded of reversible equations. The information paradox is exactness (unitarity) meeting irreversibility (evaporation) with no rule for how they share the books.

That is the pattern. *The sixteen are what happens when a world with two kinds of direction is described in a language that has only one.*

8 What kind of answer could close them

If the diagnosis is right, it constrains the cure sharply — and the constraints are worth stating before any proposal, because they are what makes a proposal checkable rather than merely appealing.

It must be structural, not parametric. Adding a field, a symmetry, or a parameter keeps the input/output boundary exactly where it was. What is needed is a change in what the framework takes as given.

It must supply two kinds of direction, intrinsically. Not two kinds of behavior imposed on similar directions, but two directions that differ in their own nature — one whose transport is closed, protected, and reversible, and one whose transport is open, priced, and final. The distinction must be topological, since only topology gives exactness that no dynamics can spoil.

It must be one answer, not sixteen. Sixteen mechanisms, each fitted to its problem, is what the field already has. A single structure that addresses all sixteen is a much stronger and much more

dangerous claim, because a single structure can be wrong all at once.

It must produce numbers. An account that explains why the constants exist but not what they are has moved the problem, not solved it. The test of a structural claim is whether measured quantities come out of it with nothing tuned.

It must be exposed. Any framework flexible enough to accommodate sixteen answers is flexible enough to accommodate anything, unless the answers come with named, dated ways to die.

These five requirements are demanding, and they are meant to be. A proposal that meets the first four and fails the fifth is philosophy; one that meets all five is physics, whether it turns out to be right or wrong.

9 The claim of this paper

The GG-Theory program's six-dimensional bulk carries, over every point of the four-dimensional stage, exactly two non-spatial directions — and they are of opposite topological kind. One is a compact circle, on which every path closes. One is an open interval, on which none does. Holonomy requires closed loops, and an interval has none. So one fiber is nothing but memory: everything on it is quantized, gauge-protected, transported by a group with inverses. The other can hold no memory at all: its transport composes forward only, a semigroup, and every step it takes is final. That is the two kinds of direction the diagnosis asked for, and it is not an addition to the program — it is a reading of a structure the constitution already wrote for other reasons. Part II builds it once, carefully, including the argument that one fiber of each kind is the constitutional *minimum*: a bulk with two circles would conserve everything and decide nothing; a bulk with two intervals would decide everything and keep nothing. Being needs holonomies; becoming needs a semigroup; a world that both is and becomes needs one of each.

Parts III–VI then spend that reading on the sixteen, in the order of Table 1, at essay length or fuller. The family of problems about exactness is answered by the circle: what is protected is protected topologically, and a class cannot drift, cannot vary from place to place, and cannot be renormalized. The family about one-wayness is answered by the interval: what is final is final algebraically, because a semigroup has no inverses to undo it with. The problems that were hardest — measurement, the information paradox, the arrow, the dark trio — are precisely those that need both fibers at once, and they are hardest in the old language for the same reason they are tractable in this one.

Two commitments govern the whole. *Nothing new is derived here*: every equation, number, and theorem is proved in a cohort paper and carried at its parent's grade, with each conditional and flagged claim marked in place. And *everything is exposed*, though not all of it in the same way: Part VII collects the named measurements — a resonance at 3.849 TeV, a haloscope line at 1.95 GHz, a tensor-to-scalar ratio near 0.0038, an isocurvature null, a large-scale statistics anomaly — on which six of the sixteen treatments die outright, and states how the remaining ten are exposed through the ledger they all spend. A reader who finds the anatomy attractive should go to that table first, and check that the paper has made itself killable before deciding whether it is right. One last framing, before the anatomy is built. [Wigner \(1960\)](#) called the effectiveness of mathematics in the natural sciences unreasonable — a mystery he thought physics had no right to expect. If

the sixteen problems above share the diagnosis proposed here, the mystery is smaller than it looks: mathematics describes the world well because the world’s non-spatial structure *is* the mathematics — a circle and an interval, a group and a semigroup — and the equations that work are the ones that happen to have been written in the right alphabet.

10 How this paper is organized

Part II opens with the program in its four development steps — the 6D bulk (A1–A4), the projection to 4D (A5–A7), the applications (A8–A11), and the white papers — and then builds the instrument: the two-fiber anatomy, developed once with its equations, its primer, its character table, its minimality argument, its determinism triad, and the map of its deployment across the cohort. Parts III–VI then treat the sixteen problems in the four categories of Table 1: the Standard Model (Problems 1–4), cosmology (Problems 5–8), the foundation of particle physics (Problems 9–12), and the foundation of the cosmos (Problems 13–16). All sixteen are developed at length: Problems 2, 7, 9, 10–11, 12, and 13 carry the campaign’s fullest quantitative apparatus, and the remaining entries are essay-length developments at the same register — the problem posed plainly, the anatomy’s answer built, the grades stated, and the kill conditions staked. Part VII is the Discussion: significance, contrasts, objections and questions, the honest-status ledger, the consolidated number audit, and the falsifier table with its decision calendar. Part VIII concludes.

Reading paths: the physicist in a hurry reads Part II and the Problem banners; the skeptic reads Part II, then §47 (the honest ledger) and §48 (the ways to be wrong); the student reads straight through — the paper assumes gauge theory and cosmology at the first-year graduate level and nothing of the cohort.

Part I in one paragraph, and what comes next

Sixteen problems, then. Four of them are the Standard Model admitting what it cannot compute; four are cosmology asking what happened before its equations start; four are the foundations of matter; four are the foundations of the arena itself. Their median age is seventy years, twelve of the fifteen dated entries predate 1976, and not one has yielded to the strategy the discipline has used on all of them — attack each with a tool built for it. What they share is more interesting than what separates them: every one asks the framework a question the framework’s own vocabulary cannot phrase, and they sort, without being forced, into problems of exactness and problems of one-wayness.

That sorting is the clue, and Part II follows it. It reviews the program that produced the anatomy — four steps, from the bulk to the projection to the applications to these two white papers — and then builds the instrument once, with its equations, so that Parts III to VI can use it sixteen times without rebuilding it.

Part II

The Anatomy

The Program in Four Steps, and One Exact Statement about Its Two Hidden Directions

11 The statement

Every result in this paper is *sorted by* one sentence — and *produced by* the cohort’s derivations, a distinction §44 insists on and this Part will not blur. The sentence is elementary enough to prove in a paragraph:

Holonomy requires closed loops, and an interval has none.

Take a connection — any connection — on a fiber bundle. Parallel transport along a path compares the fiber at the end with the fiber at the start; but only when the path *closes* does the comparison become an invariant statement about the geometry itself, because only then are the start and the end the same fiber. That invariant — the holonomy of the loop — is the entire gauge-invariant content of the connection: by the Wilson-loop reconstruction, a gauge field *is* its holonomies, no more and no less. On a compact circle, every winding path closes; the circle is, in this precise sense, nothing but closed loops, and everything a connection does there is holonomy — quantized by the winding integers, protected because an integer has nowhere to move, composed by a *group*, with every transport invertible. On an interval, no path closes; there is no loop to hold a holonomy, hence no protected content at all; and because the physical transport along it composes only forward, its composition law is a *semigroup* — no inverses, ever.

The six-dimensional bulk of GG-Theory (Arisaka, 2026, A2-GG6) places exactly one fiber of each kind over every point of the Lorentzian stage $\mathcal{M}_4$:

$$\mathcal{M}_6 = \mathcal{M}_4 \times I_r \times S_\theta^1, \quad I_r = [0, K], \quad K = 35, \quad S_\theta^1 \cong S^1, \quad (1)$$

the scale interval I_r — the fifth dimension, the renormalization-group coordinate $r = \ln(E_{\text{GUT}}/\mu)$ made geometry — and the phase circle S_θ^1 — the sixth dimension, the gauge phase made geometry. The statement above then sorts the pair completely:

The circle remembers; the interval forgets.

This Part does two jobs, in order. First it reviews the program the sentence serves: the four development steps of GG-Theory — the bulk, the projection, the applications, and the white papers (§12) — so that the anatomy is met as what it is, the visual language of an audited structure, not a metaphor in search of one. Then it builds the instrument once: the primer with its equations

(§13–14), the two characters (§15), the reason the pair is a constitutional minimum (§16), the determinism it enforces (§18), and the one place the fibers multiply (§19). Everything after Part II is application.

12 The program in four steps

The two-fiber anatomy did not arrive alone, and it cannot be judged alone: it is the visual language of a program that was built in a definite order, each stage standing on the one before. Before the instrument is developed, this section walks that order once — four steps, each anchored in named papers, each summarized with its key equations and the intuition that goes with them. A reader who holds the four steps holds the whole cohort in outline; a reader who skips to the anatomy will still find every claim below cited where it is used.

Table 3: The GG-Theory program in four steps. Each step stands on the one above; the white papers (Step D) are the synthesis layer, and this paper is the second of them. Step A (A1–A4) is the arena: one geometry for gravity and the five gauge forces, anomaly-free, with zero free parameters. Step B (A5–A7) is the projection to four dimensions and what it buys — measurement, the quantum postulates, the engine of symmetry breaking, the information ledger. Step C (A8–A11) is the applications, derived and graded. Step D is the two white papers.

Step	Papers	What is built	What it yields
A	A1–A4	GGEP: the 6D bulk, its group, its books	one geometry for gravity and the five gauge forces; anomaly-free; zero free parameters
B	A5–A7	OGGEP, GDOS, GRIP: the projection to 4D	measurement, the quantum postulates, the engine of symmetry breaking, the information ledger
C	A8–A11	the applications	quantum mechanics, the Standard Model, Λ CDM, and the origin of life and mind, derived and graded
D	W1, W2	the white papers	the synthesis: symmetry read historically (W1) and the two-fiber anatomy read structurally (W2 — this paper)

Figure 1 draws the same architecture as a building: each story rests on the one below, and the two white papers are the view from the roof.

12.1 Step A: one geometry, exact books, no dials (A1–A4)

The constitution. The program begins not with a Lagrangian but with a constitution: four axioms and seven postulates (Arisaka, 2026, A1-Constitution), written once and never amended mid-argument. Two matter most here. AX-2 is GGEP — the *geometry–gauge equivalence principle* — which declares that gravity and the gauge forces are not two kinds of physics to be glued together but one composite connection on one bulk: the gauge fields are geometry exactly as the metric is. AX-3 is OGGEP (Step B’s subject): whatever observation is, it is a projection of that bulk, not a view from outside it. Alongside the axioms sits MSMF, the parsimony clause: the minimal structure

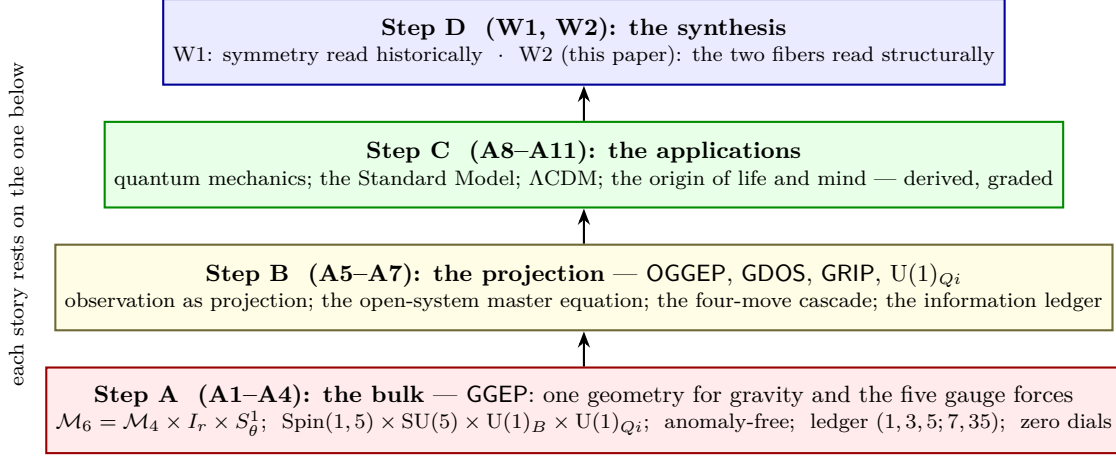


Figure 1: The program as a building. Step A builds the six-dimensional bulk with exact books and no dials; Step B derives how that bulk projects to the four-dimensional physics laboratories measure; Step C applies the pair to the four great frameworks; and Step D — the white papers — states what was learned. The two-fiber anatomy developed in this Part is Step D’s instrument: the single picture in which all four stories are visible at once.

with maximal function — no field, dimension, or constant may be added for convenience. The constitution’s role in everything that follows is exactly a constitution’s role: when a later step seems to demand a new ingredient, the demand is refused, and the refusal — as Problems 4, 6, and 15 will show — is where the explanatory power comes from.

The bulk and its group. On that charter, A2 (Arisaka, 2026, A2-GG6) proves the arena is forced: the six-dimensional bulk of Eq. (1), $\mathcal{M}_4 \times I_r \times S_\theta^1$ — the four-dimensional stage, the open scale interval, the compact phase circle — carrying the composite connection of the group

$$G_{\text{bulk}} = \text{Spin}(1, 5) \times \text{SU}(5) \times \text{U}(1)_B \times \text{U}(1)_{Qi}. \quad (2)$$

The intuition for each factor: $\text{Spin}(1, 5)$ is the six-dimensional spacetime symmetry — gravity, now including the two hidden directions, so that “curvature” and “gauge field” are one word; $\text{SU}(5)$ is the single non-abelian factor from which the strong and electroweak forces descend — one gauge structure at the top, not three glued at the bottom; $\text{U}(1)_B$ books baryon number; and $\text{U}(1)_{Qi}$ books the quantum of information (Step B). Unification here is not a hope deferred to high energy: it is the statement that Eq. (2) acts on Eq. (1) as one connection, and everything laboratories distinguish — the four interactions of Problem 2 — is that one object read on different fibers.

The integer ledger. The same paper derives the program’s five integers with their closure identities,

$$(M, N, L; J, K) = (1, 3, 5; 7, 35), \quad J = 2N + 1, \quad K = LJ = 5 \times 7, \quad (3)$$

and the reader should pause on how strange and how strong this is. M counts the time direction; $N = 3$ the color triplicity; $L = 5$ the rank structure of the unified group; $J = 7$ the chiral steps of the flavor alphabet; and $K = 35$ the depth of the descent — and they are not five independent inputs but one overdetermined web: J is fixed by N , K by L and J . Five small integers, two identities, zero freedom. Every number in the cohort — masses, angles, densities, the age of the universe — is arithmetic in these five and the constants of Step A’s last paper. Two examples, derived in [Arisaka \(2026, A9-SM\)](#) and audited in Problem 4:

$$\begin{aligned}\alpha^{-1}(0) &= 2^J + N^2 = 128 + 9 = 137 \quad (\text{measured } 137.036), \\ \sin^2 \theta_W &= \frac{L^2}{4N^3} = \frac{25}{108} = 0.2315 \quad (\text{measured } 0.2312).\end{aligned}\tag{4}$$

The intuition to carry: the fine-structure constant is not a dial that happened to stop at 137.036; it is a *count* — 2^J states of the chiral alphabet plus N^2 of the generation square — and counts are the kind of thing the compact fiber protects.

The books balance. A theory whose gauge structure lives on a compact fiber must pass one unforgiving audit: anomaly freedom. An anomaly is a quantum bookkeeping failure — a classical symmetry whose books do not close at one loop — and in six dimensions the audit is harsher than in four. A3 ([Arisaka, 2026, A3-BI6](#)) closes it: the bulk of Eqs. (1)–(2) is locally and globally anomaly-free by the six-dimensional **Green–Schwarz** mechanism ([Green and Schwarz, 1984](#)), without supersymmetry, and the audit is not merely passed but *productive*: it locks the coefficient vector $(1, -1, -\frac{2}{5}, -\frac{2}{5})$ and the 5:2 trace ratio that later fix the Kaxion’s couplings (Problem 7), and it supplies the dual-lock identity $L(2N + 1) = M^2 + N^2 + L^2$, which is what selects N — and therefore J , and therefore K — from inside the audit rather than by hand (Problem 6). The intuition: on the circle, anomaly coefficients are integers, and integers cannot run — so an audit passed once is passed forever, and its byproducts are exact.

Zero free parameters. Step A closes with A4 ([Arisaka, 2026, A4-Euclid](#)): the five dimensionful constants of nature — $\hbar$, c , G_N , k_B , and the Arisaka constant Q_B — reconstructed as the conversion factors of the geometry’s directions, one per kind of dimension: $\hbar$ prices the circle’s tick, G_N the interval’s descent, c converts the stage’s directions, k_B and Q_B price the boundary’s exchange and deposit. Nothing else dimensionful exists to choose, and nothing dimensionless is free: what remains is Eq. (3)’s arithmetic. This is the precise sense in which the program has *zero free parameters* — not that its numbers are few, but that its numbers are counted, and the count is closed (Problem 4 conjugates all twenty-eight Standard-Model entries in this grammar; Problem 14 explains why setting $\hbar = c = G_N = k_B = 1$ was always lawful).

12.2 Step B: the projection — how a 6D bulk becomes 4D physics (A5–A7)

Step A builds a six-dimensional object with exact books. But every experiment ever performed lives on the four-dimensional stage. The program’s second stage is the account of that gap — and it is here, not in Step A’s geometry, that quantum mechanics enters.

OGGEP: observation is projection. AX-3 declares that an observation is not a view of the bulk from outside but a *projection* of it: the fiber coordinates are marginalized — integrated over — and what survives to the stage is exactly the fiber content that projection cannot erase: the circle’s holonomy classes and the interval’s deposited addresses. The reader already owns the intuition from Part I: a measurement is a *read*. What the projection can reach, it reads; what it reads, it writes; and what it writes, it cannot unwrite.

Figure 2 draws the projection: over each point of the stage sits the pair of hidden directions, and an observation is the map that forgets them.

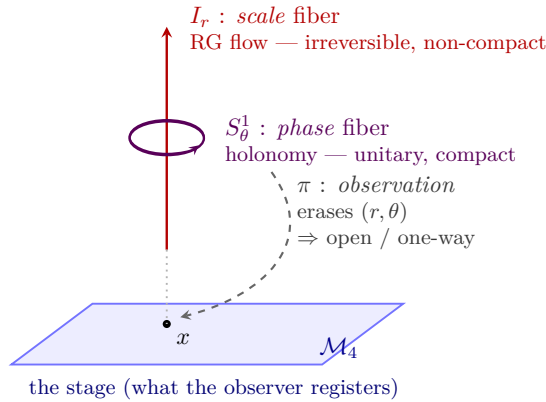


Figure 2: Observation as the projection $\pi : \mathcal{M}_6 \rightarrow \mathcal{M}_4$ (adapted from Arisaka, 2026, W1-Symmetry). Over each stage point x sits the non-spatial pair (I_r, S_θ^1) . The compact phase circle carries the coherent, unitary content — its holonomy is the Aharonov–Bohm phase of §13 — while the open scale interval carries the irreversible content, its forward-only flow becoming the dissipator of Eq. (5). Because both fiber coordinates are non-spatial, no laboratory protocol resolves them; every registration marginalizes the fiber, so π is non-invertible and the stage dynamics is necessarily open. Unitary quantum mechanics is the unreachable limit in which the fiber is never read.

GDOS: the runtime, as an equation. A5 (Arisaka, 2026, A5-GDOS) converts OGGEP into dynamics. Because the projection is always on — the stage never stops being coupled to the fibers it marginalizes — the effective four-dimensional dynamics is that of an *open* system, and its generator is derived, not postulated:

$$\frac{d\rho}{dt} = -\frac{i}{\hbar} [H, \rho] + \mathcal{D}[\rho], \quad (5)$$

a master equation of Lindblad form, in which the two fibers are visible as the two terms. The commutator is the circle’s half: unitary, reversible, phase-carrying — the Schrödinger evolution, exactly as the textbooks teach it. The dissipator $\mathcal{D}$ is the interval’s half: completely positive, one-way, record-forming — the term the textbooks smuggle in by hand as “collapse” arrives here as the boundary’s own bookkeeping. The textbook postulates — Hilbert space, unitary evolution between readings, the Lüders update at a reading — follow as theorems of Eq. (5)’s relaxation, and the Born weights,

$$p_k = |\langle k | \psi \rangle|^2, \quad (6)$$

are *produced* rather than assumed: the dissipator relaxes configurational statistics onto the squared-amplitude measure, monotonically, at a rate the port coupling sets — carried in the cohort at the relaxation grade, with the one remaining analytic step (the field-grade representation) named openly (Problem 1 states both halves of that sentence with equal weight).

GRIP: the engine. A6 (Arisaka, 2026, A6-GRIP) supplies the runtime’s engine — the cascade

$$\text{GRIP} := \text{DGI} + \text{GFF} + \text{GSSB} + \text{GGA}, \quad (7)$$

read left to right as a sentence: *Dynamical Gauge Invariance* holds the top open (every gauge equivalence intact, nothing yet committed); the *geometric free-energy functional* supplies the landscape (the configuration falls along its gradient); *geometric spontaneous symmetry breaking* selects (the fall must land somewhere); and the *geometric ground-state attractor* closes (the landing is the stratum’s deepest floor, by Morse analysis — and there is nowhere else to land, on the uniqueness condition §18 names). The cascade has two strokes, and they are the two fibers operating: GRIP-In, the circle’s stroke — closed-loop relaxation on a fixed landscape, outcomes banked in protected classes — and GRIP-Out, the interval’s stroke — the one-way reorganization of the landscape itself, which no gradient flow generates and no operation reverses. Everything the later Parts call “the groove” (Problems 8 and 15) is Eq. (7) plus the Morse uniqueness, at the grade §18 prints for it; the weak interaction (Problem 2) is the cascade caught operating in the laboratory.

The stages, fiber-resolved: custody of transport, custody of data. The strokes are the coarse mapping; the runtime companion now carries the fine one (Arisaka, 2026, A6-GRIP, the stage-custody subsection), and it earns a paragraph here because it is this paper’s fork applied to its own engine. The strokes are named for their *products*: GRIP-In is the circle’s stroke because its outcome is banked in circle classes; GRIP-Out the interval’s because it changes the landscape and banks nothing. The stages are named for their *transport*: the equivalences DGI holds intact compose as the circle’s group — the circle is the bulk’s only gauge bundle, the interval’s “structure group” being the one-way dilatation semigroup (Arisaka, 2026, A8-QM) — while the descent that executes $\text{GSSB} \rightarrow \text{GGA}$ composes as the interval’s semigroup, being the long-time boundary flow whose generator is the projected I_r dilatation (Arisaka, 2026, A5-GDOS). The middle stage crosses, and the crossing is the content: GSSB reads circle data (its order parameters are Wilson-line phases), runs on the interval (the one-way act of selection), and deposits its outcome back into the classes the circle protects. GSSB stands to symmetry breaking exactly as the write stands to measurement (Problem 1): one seam-event shape, two instances. The sentence to keep: *the circle states the alternatives; the interval performs the selection; the attractor is the circle’s receipt*.

Figure 3 reproduces the engine’s full diagram: the four moves in the central column, the axioms that force them on the left, the information pillars that filter them on the right, and the two strokes at the bottom.

U(1)_{Qi}: the information ledger. A7 (Arisaka, 2026, A7-Qi4) completes the projection stage with the fourth bookkeeping: memory and its price. A stable bit is holonomy-class data — storage

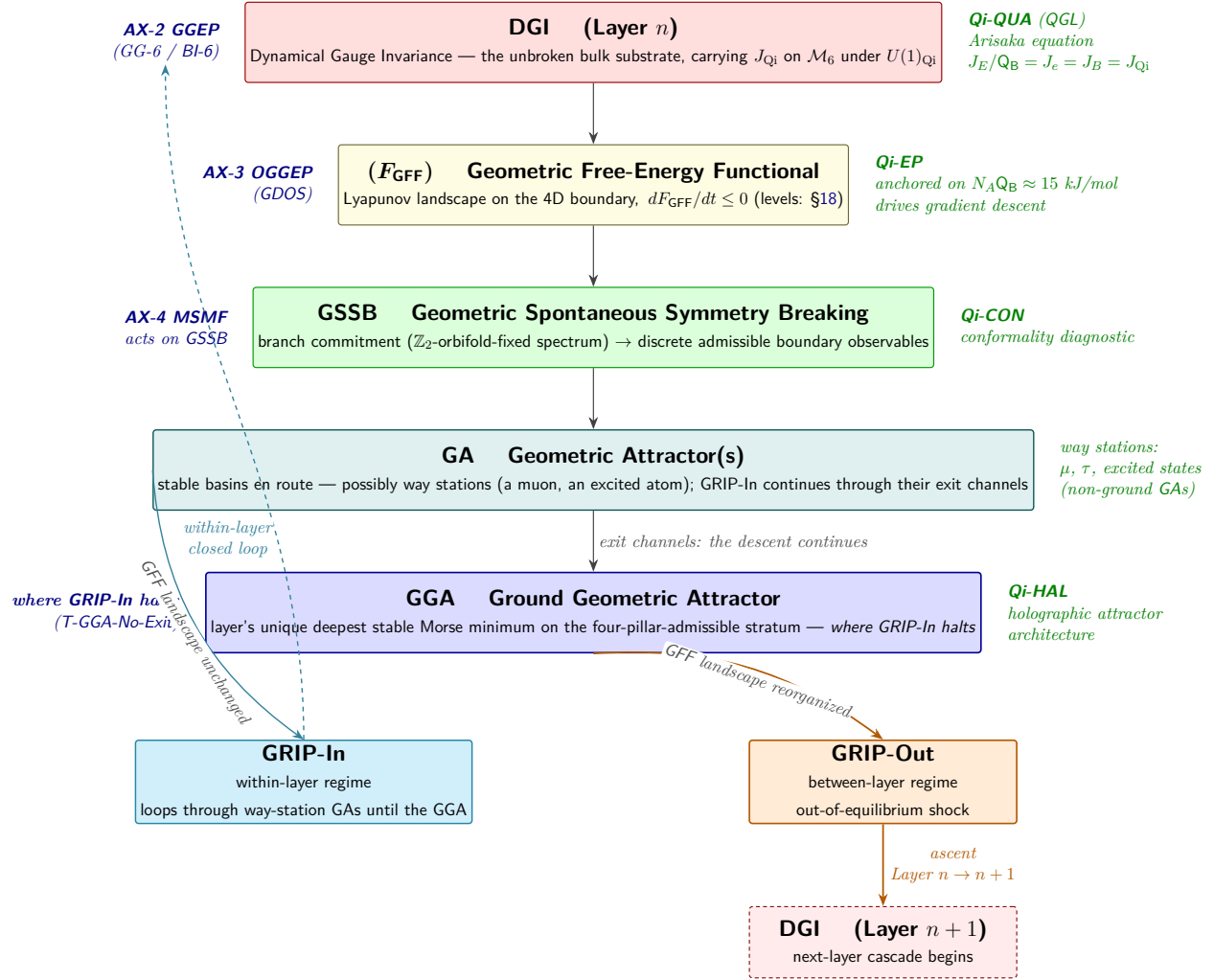


Figure 3: The GRIP engine: four moves, two regimes, one ground state (reproduced from Arisaka, 2026, A11-Origin; the engine is built in Arisaka, 2026, A6-GRIP). The central column is the four-move cascade of Eq. (7); the constitutional axioms (left) force the moves; the four information pillars (right) filter the admissible minima. At bottom, the two strokes: GRIP-In (cyan) loops *within* a layer to its ground state, unique on admissible strata (§18) — the circle's stroke — and GRIP-Out (orange) reorganizes the landscape and opens the next layer — the interval's stroke. The two-fiber anatomy is this diagram's grammar: everything cyan is closed-loop and reversible-in-form; everything orange is one-way. Custody, fiber-resolved: everything cyan *banks* on the circle; the algebra its descent composes under is the interval's.

on the circle is free, because integers pay no maintenance — while erasure is an interval-side write, and every write has a floor price:

$$\Delta E \geq k_B T \ln 2 \quad \text{per bit erased,} \quad (8)$$

Landauer’s bound (Landauer, 1961), read here not as an analogy between information and thermodynamics but as the same ledger: $U(1)_{Q_i}$ ’s charge is the quantum of information, Q_B is its unit price, and the two laws of thermodynamics are the two fibers’ conservation laws (Problem 14). The intuition: the universe keeps two kinds of books — what it is (free to keep, impossible to alter) and what it has done (impossible to keep from growing, priced per line).

12.3 Step C: the applications — four theories, derived and graded (A8–A11)

With the bulk built and the projection derived, the program’s third stage is deliberate: take the four great descriptive frameworks of modern science and derive each as a face of the same object, at declared grades.

Quantum mechanics (A8). A8 (Arisaka, 2026, A8-QM) locates every quantum peculiarity on the anatomy: superposition and interference are the circle’s transported phase; measurement is the interval’s write (Eq. (5)); the Born rule is the relaxation result of Eq. (6); decoherence is the write’s microscopic face; and the classical world is the registered record. Problem 1 is this paper’s plain-English carrying of that Part, and the F25 relic — the prediction that the largest cosmological scales retain a computable primordial-statistics deficit — is its observational exposure.

The Standard Model (A9). A9 (Arisaka, 2026, A9-SM) is the codebook: all twenty-eight Standard-Model parameters derived or graded from Eq. (3)’s arithmetic, each entry carrying its provenance. The template chain, worked once here because Parts III–VI quote it constantly: the interval’s depth sets the lock scale (Eq. (15) below, $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} = 3.849 \text{ TeV}$), and the circle’s fraction dresses it into the electroweak vacuum,

$$v = M_{\text{lock}} \left(\frac{2}{L} \right)^N = 3849 \text{ GeV} \times \left(\frac{2}{5} \right)^3 = 246.3 \text{ GeV} \quad (\text{measured } 246.22), \quad (9)$$

a circle label dressing an interval address — the grammatical form (§19) that every mass in the codebook repeats. Problems 2, 3, and 4 unpack the sector.

The cosmos (A10). A10 (Arisaka, 2026, A10-Cosmos) derives Λ CDM’s six numbers with no dial. The inventory is fiber-volume arithmetic — the Hopf reading gives

$$\Omega_m = \frac{1}{\pi} = 0.318, \quad \Omega_b = \frac{1}{2\pi^2} = 0.0507, \quad \Omega_\Lambda = 1 - \frac{1}{\pi} = 0.682 \quad (\text{meas. } 0.315, 0.049, 0.685), \quad (10)$$

— the launch is the derived plateau roll with $n_s = 0.9634$ and $r = 0.0038$ (Eq. (31), Problem 5); the chronology is exact, $d \ln t / dr = 2$ (Eq. (44), Problem 13); and the terminus is the seesaw

$m_\Lambda = M_{\text{lock}}^2/M_{\text{Pl,red}} \simeq 6.1 \text{ meV}$ (Problem 7). The intuition to carry from Step C’s cosmology: the history of the universe is the interval traversed once, and every era is an address.

Figure 4 shows the whole of Step C’s cosmology on one axis: the descent drawn to scale, every epoch an address.

Life and mind (A11). A11 (Arisaka, 2026, A11-Origin) runs the cascade of Eq. (7) from the GUT edge to the biosphere: eighteen GRIP events, each a stratum’s floor — unique on the condition §18 names — each banked before the next begins — nucleons, nuclei, atoms, molecules, autocatalysis, code, cognition — and proves the GGA theorems (ground-state uniqueness, no-exit) on which the whole chain’s stability rests. Its four closing words — not contingent, not lucky, not designed, *forced* — are the register in which Problems 8 and 15 answer the multiverse, and this paper closes on them.

12.4 Step D: the fourth step — the white papers (W1, W2)

Steps A–C are research: they build, project, and apply. The fourth step is different in kind — synthesis: stand back from the twenty-two papers and ask what single thing has actually been learned. The cohort’s answer comes in two white papers, one historical and one structural, and they are deliberately a pair.

GG-W1-Symmetry (Arisaka, 2026, W1-Symmetry) is the *diachronic* reading: it walks the century of symmetry and conservation — Noether’s two theorems, the Bianchi identity, Wilson’s loops, the Green–Schwarz mechanism, Hopkins–Singer quantization — and shows the old conviction “symmetry causes conservation” loosening step by step until what remains conserved is an integer with nowhere to move. Its capstone is the determinism triad (§18): symmetry breaking re-understood as symmetry *reading* — the one-way playback of a groove that was never symmetric.

This paper is the *synchronic* reading: the same content, organized not by history but by structure. The single thing learned, in this paper’s language, is the anatomy: the bulk’s two hidden directions are fibers of opposite topological kind, and that opposition — circle and interval, group and semigroup, memory and act — is where the program’s explanations live. W1 shows *how physics arrived* at the doorstep; W2 opens the door and walks the house — the sixteen rooms of Part I. The remainder of this Part now builds the instrument the walk requires: the two characters in full, the reason the pair is minimal, the determinism it enforces, and the working images and grade discipline used on every page after.

13 A one-page primer: holonomy, from the bench to the bulk

For the reader meeting holonomy as a physical (rather than mathematical) object for the first time, three rungs connect the laboratory to Eq. (1).

Rung 1: the tabletop. The Aharonov–Bohm experiment is holonomy made visible: an electron beam split around a solenoid interferes with itself, and the fringe shift measures the phase

$$\Delta\varphi = \frac{q}{\hbar} \oint_C A \cdot dl = \frac{q\Phi}{\hbar}, \quad (11)$$

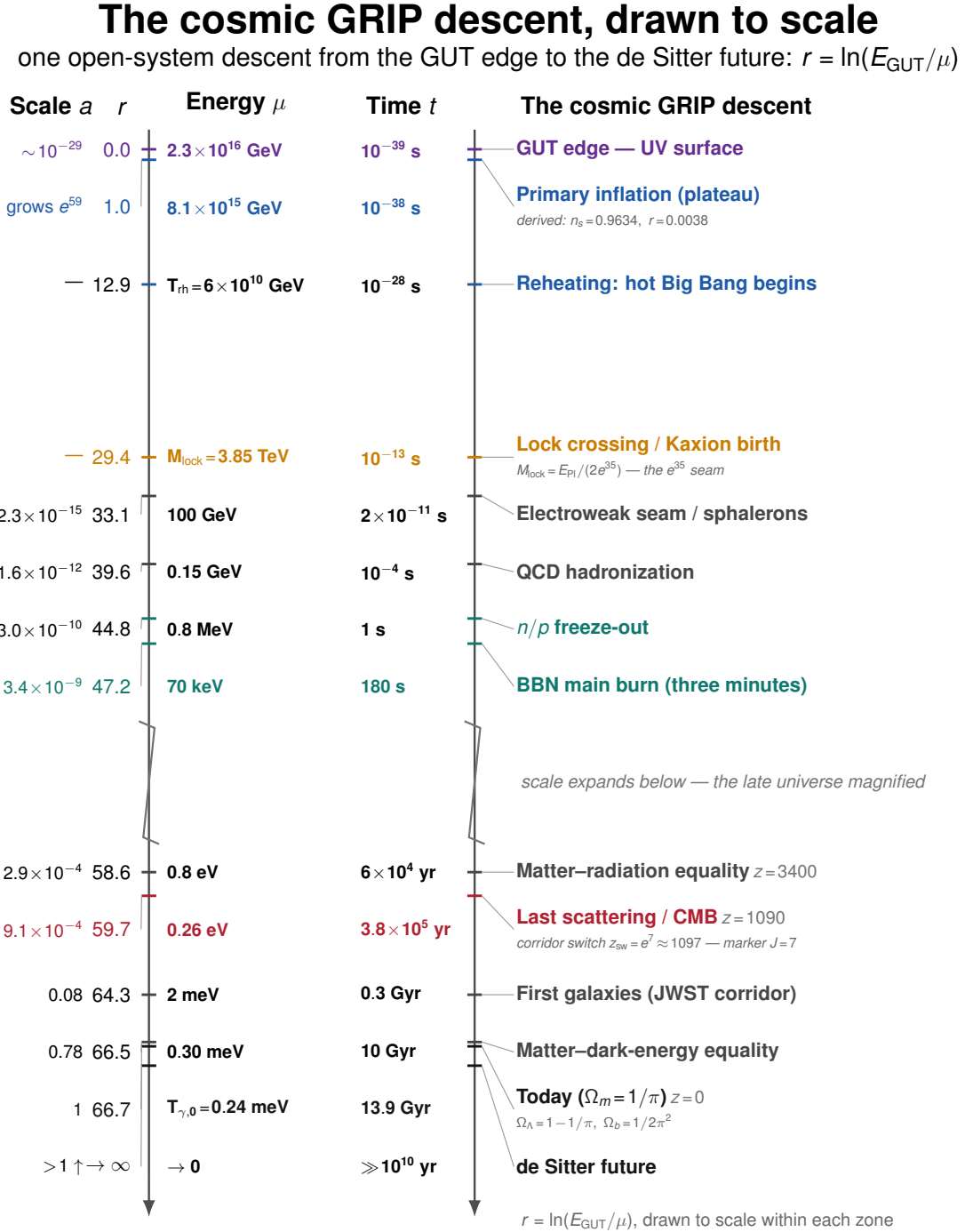


Figure 4: The cosmic GRIP descent, drawn to scale on $r = \ln(E_{\text{GUT}}/\mu)$ (reproduced from Arisaka, 2026, A10-Cosmos). One open-system descent from the GUT edge ($r = 0$) to the de Sitter future, read simultaneously in four quantities — energy μ , time t , and the scale factor a , each against the radial depth r — with the late universe magnified beneath the break. Highlighted rows carry the derived markers this paper quotes throughout: the plateau tilt and tensor ratio ($n_s = 0.9634$, $r_T = 0.0038$), the lock $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-35} = 3.85$ TeV, the corridor switch $z_{\text{sw}} = e^7$ (the ledger integer $J = 7$), and today’s π -locked inventory of Eq. (10). Nothing on the axis is fitted: the figure *is* the interval, traversed once.

the loop integral of the potential — equivalently the enclosed flux Φ — around the closed circuit C : a quantity that survives even where the field strength vanishes along the entire path. Read the equation's three symbols as the anatomy in miniature: q is a protected charge, C must *close* for $\Delta\varphi$ to mean anything, and $\hbar$ — Step A's circle-side constant — is the exchange rate between geometry and phase. Two lessons ship with the apparatus. The phase is *loop* data: no measurement along an open segment reveals it, because only the closed comparison is gauge-invariant. And the phase is *robust*: deform the arms at will, and as long as the winding about the solenoid is unchanged, the shift is unchanged. Memory that survives deformation, readable only on closure — that is the whole character of the circle, already on the bench.

Rung 2: the reconstruction. Wilson's observation elevates the bench fact to a definition: the gauge-invariant content of any gauge field is exactly its Wilson loops,

$$W(C) = \mathcal{P} \exp\left(\frac{iq}{\hbar} \oint_C A \cdot dl\right), \quad (12)$$

the path-ordered exponential of Eq. (11)'s integrand over every closed curve C — a connection *is* its holonomies, no more and no less. From this the two fiber characters follow as pure logic. A compact fiber supports noncontractible loops, so a connection there has invariant content: quantized windings, protected phases. A contractible fiber with boundary — an interval — supports none, so a connection there has *no* gauge-invariant content at all: whatever happens along it is convention until it is registered elsewhere. The statement of §11 is not an analogy built on the bench experiment; it is the same theorem, read for two different base spaces.

Rung 3: the transport algebra. Composition closes the primer, and it deserves its own pair of displayed lines, because the whole paper is the difference between them. Transports around the circle compose as a *group*:

$$U(\theta_2)U(\theta_1) = U(\theta_1 + \theta_2), \quad U(\theta)^{-1} = U(-\theta) \quad \text{always exists;} \quad (13)$$

every loop can be retraced, and the algebra is the algebra of things that can be undone. Physical transport along the scale interval — the renormalization flow, the cosmic descent — composes as a *semigroup*:

$$T(r_2)T(r_1) = T(r_1 + r_2) \quad \text{for } r_1, r_2 \geq 0 \quad \text{only,} \quad T(r)^{-1} \text{ does not exist;} \quad (14)$$

coarse-graining has no inverse, so the flow runs one way and each step is final. The two lines look almost identical — one composition law, one addition of parameters — and differ in one clause: whether the inverse exists. That single clause is the group/semigroup split, and it is the property the rest of this paper spends: *what has inverses can promise; what lacks them can happen*.

Two premises, graded apart. The two displayed lines are not established the same way, and the distinction matters more here than anywhere else in the paper, so it is drawn now and kept

throughout.

Premise (T), topological. Eq. (13), and the absence of any protected content along the interval, follow from $\pi_1(S_\theta^1) = \mathbb{Z}$ and $\pi_1(I_r) = 1$ and from nothing else. They hold for any connection, any field content, any Lagrangian. Nothing physical is assumed. This is the premise that earns the sentence *holonomy requires closed loops, and an interval has none*, and it is unarguable.

Premise (D), the boundary law's. The *failure of the inverse* in Eq. (14) is not topological, and this paper does not claim that it is. Parallel transport along a path in I_r is perfectly invertible — Appendix 63 gauges the interval's connection away altogether. What lacks an inverse is the *physical* transport along r : the renormalization flow and the cosmic descent, whose composition law is Kadanoff's Eq. (65) and whose non-invertibility is the non-injectivity of blocking — many microscopic configurations to one block, and no operation restores what was never kept. That is derived rather than assumed, but it is derived in Step B, from the open-system chain and OGGE's compulsory projection.

Keeping the two apart costs the paper nothing it uses and saves it from a claim it cannot defend. The characteristic assertion of this program is not that topology alone makes time run forward. It is that irreversibility is *algebra rather than statistics* — a property of how transports compose, not a matter of how many degrees of freedom happen to be in the room — and (T) and (D) together deliver exactly that. (T) says the interval has nothing to protect; (D) says what happens along it cannot be undone. A framework needs both, and this one has both, from two different places.

14 The instrument, quantified

These four equations carry every later Part, so here is what each one buys.

Eq. (11) (the phase) is why the circle's content is physical. A quantity readable only on closed circuits is untouchable by anything local: no field redefinition, no gauge choice, no smooth deformation reaches it. Everything the cohort banks on the circle — charges, parities, the flavor alphabet, the ledger integers of Eq. (3) — inherits this protection.

Eq. (12) (the reconstruction) is why the circle's content is everything. Since a connection is its holonomies, a fiber with no closed loops carries a connection with no invariant content at all — which is the precise sense in which the interval *forgets*: not that its record fades, but that there was never a gauge-invariant record to keep. What the interval does instead is act — and its acts are registered on the boundary, priced by Eq. (8).

Eq. (13) (the group) is the quantum half. Unitary evolution, superposition, interference, reversibility between measurements — the entire coherent face of quantum mechanics is transport with inverses, and it lives where the inverses live: on the compact fiber. Energy conservation is this line's Noether charge (Problem 14).

Eq. (14) (the semigroup) is the classical half. Measurement, decoherence, the renormalization flow, entropy growth, cosmic history, aging — the entire irreversible face of physics is transport without inverses, and it lives where the inverses fail: on the open fiber. The second law is this line's signature (Problem 14), and the dissipator of Eq. (5) is its generator.

One instrument, four readings — and the reader now holds, in five displayed equations, the entire

technical content of the sentence *the circle remembers; the interval forgets*. The rest of this Part gives the pair their characters, their minimality proof, and their working images; Parts III–VI spend them.

15 The two characters

Table 4 is the paper’s reference card, and Figure 5 is its portrait. Each row is a theorem-shaped statement of a cohort paper, cited in place; the table’s contribution is only the alignment.

Table 4: The reference card: the two non-spatial fibers, character by character. Each row is established in the cited cohort paper; the table aligns them. The ten rows run from topology and holonomy through the algebra of transport — a group on the circle, a semigroup on the interval — to the character of the content each carries (quantized against continuous), the constant each supplies ($\hbar$ against G_N), the conservation law each owns (the first law against the second), the field each coordinate becomes (the Kaxion against the inflaton), and the face of time each shows (the tick against the arrow).

	The circle S^1_θ (6th)	The interval I_r (5th)
Topology	compact, closed: all loops	non-compact, open: no loops
Holonomy	everything — the fiber <i>is</i> its holonomies	none — nothing to protect
Transport	a group (inverses exist)	a semigroup (forward only)
Content	quantized: windings, phases, parities, charges	continuous: scales, addresses, rates
Behavior	remembers: classes do not age	forgets: one pass through every scale
Physical role	the gauge phase; the ledger ($M, N, L; J, K$); the flavor lattice	the RG flow; the descent; the warp e^{-2r}
Its constant	$\hbar$ — the price of a tick (Arisaka, 2026, A4-Euclid)	G_N — the residue of the descent (Arisaka, 2026, A4-Euclid)
Its conservation law	the first law: energy (nothing about it is one-way)	the second law: entropy (nothing about it repeats) (Arisaka, 2026, A5-GDOS)
Its coordinate, as a field	the Kaxion (Problem 7)	the inflaton (Problem 7)
Its face of time	the tick (Problem 13)	the arrow (Problem 13)

Three remarks make the card load-bearing rather than decorative.

The asymmetry is structural, and it has two sources. Both fibers carry Ehresmann connections; both are geometry of the same bulk; nothing in the Lagrangian distinguishes them. What distinguishes them is prior to any choice of dynamics, and it arrives in the two premises of §13. By (T), the circle has noncontractible loops and the interval has none, so one fiber can hold gauge-invariant content and the other has nothing to hold. By (D), the physical flow along the interval is the coarse-graining flow, which is not injective, so it composes forward only. Every exactness claim in this paper is traced to (T); every arrow, record and irreversibility to (T) together with (D) — and to nothing else. No thermodynamic postulate, no collapse postulate, no initial-condition

stipulation is ever added. But the reader should hold the paper to the honest form of the claim: irreversibility here comes from a compulsory projection onto a fiber that has nothing to protect, not from topology unaided.

Protection has an address. Whenever physics presents a quantity that is exact — a charge that never leaks, an anomaly coefficient that does not run, a family count that neither drifts nor renormalizes — the anatomy says where it lives: on the circle, deposited in holonomy classes that no boundary operation can continuously deform. And whenever physics presents a quantity that is *placed* — a mass, a scale, a rate, an epoch — the anatomy says where that lives too: along the interval, as an address on the fiber that forgets. The codebook paper carries this as a grammar covering all twenty-eight Standard-Model parameters: *every parameter is a holonomy-class label wearing a descent address* (Arisaka, 2026, A9-SM; Arisaka, 2026, P3-Electron).

The dictionary owns the sectors; the geometry owns the i . The real-bulk companion (Arisaka, 2026, P4-Real) adds the information-theoretic face: the complex numbers of quantum mechanics are the circle's — weight decomposition under a circle action is what manufactures the i — while records are real because registration is an interval-side write, along the fiber that carries no phase. Why complex amplitudes? Because one fiber is a circle. Why real records? Because the other is an interval.

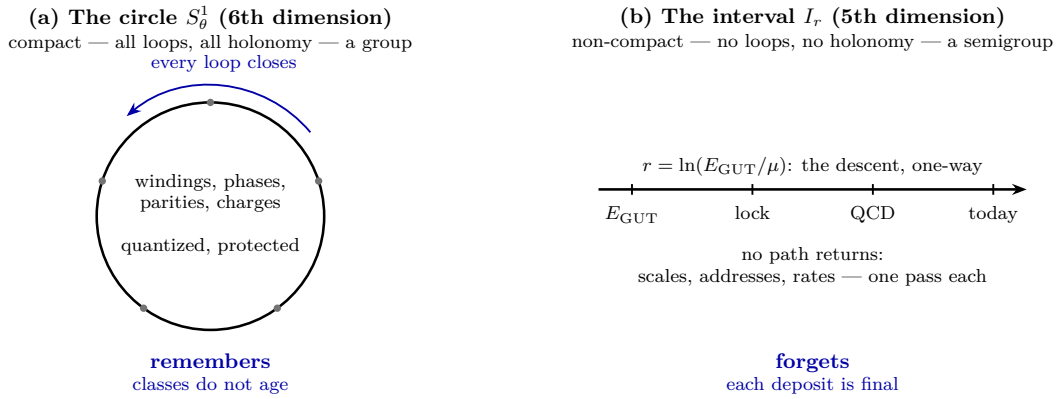


Figure 5: The anatomy. (a) The compact phase circle: every path closes, so everything a connection does there is holonomy — quantized (dots: the ledger-rational marks), gauge-protected, transported by a group. (b) The scale interval: no path closes, so nothing is protected; transport composes only forward, a semigroup; the descent visits each scale exactly once. *The circle remembers; the interval forgets* — and every consequence in Parts III–VI is this figure, applied.

16 The constitutional minimum

Why one fiber of each kind — why not two circles, or two intervals, or one fiber, or none? The constitution answers with a minimality claim that the campaign has made exact (Arisaka, 2026, A1-Constitution; Arisaka, 2026, A2-GG6).

A bulk with *two circles* would conserve everything and decide nothing. All content would be holonomy-class data; every quantity protected; no transport irreversible. There would be no arrow, no registration, no record — AX-3 (OGGEP), which makes observation a projection, would have nothing lawful to project *onto*, because a record is precisely a deposit that cannot be undone, and a two-circle world has no fiber on which anything is final. Such a world *is* but never *becomes*.

A bulk with *two intervals* would decide everything and keep nothing. No quantized charge, no protected phase, no stable atom — interference needs a phase that returns, and a charge that never leaks needs a class that cannot deform. Such a world *becomes* but never *is*: perpetual reorganization, converging on nothing, with no alphabet in which an outcome could even be written.

Being needs holonomies; *becoming* needs a semigroup. A universe that both is and becomes needs exactly one fiber of each kind — and that is what AX-2 (GGEP) writes and AX-3 (OGGEP) reads. The same counting reappears at runtime level in the GRIP engine (Arisaka, 2026, A6-GRIP): GRIP-In, the circle’s stroke — closed-loop relaxation on a fixed landscape, outcomes deposited in the quantities the circle protects — and GRIP-Out, the interval’s stroke — the one-way landscape reorganization no gradient flow generates and no operation reverses. A runtime with only GRIP-In would cycle forever deciding nothing; with only GRIP-Out, reorganize forever converging on nothing. The cascade of nature requires exactly one stroke of each kind for the same topological reason the bulk carries exactly one fiber of each kind.

17 The two counterfactuals, run slowly

The minimality argument of §16 deserves a slower pass, because the two impossible worlds it invokes are the best intuition pumps the anatomy owns.

The two-circle world. Give the bulk a second compact fiber in place of the interval. Every direction now supports holonomy; every quantity is a winding; the transport algebra is a group throughout. Walk through what is lost. There is no scale: nothing distinguishes ultraviolet from infrared, because the would-be RG coordinate now returns — physics at every resolution is periodically identified with physics at another, and “coarse-graining” is a rotation. There is no equilibrium and no approach to it: relaxation requires a lost past, and nothing is lost. There is no record: a record is a deposit that cannot be undone, and every operation now has an inverse. And so there is no *event*: things are, permanently and reversibly, but nothing ever happens, because happening is exactly the part that does not unhappen. A two-circle world is a perfect archive with no history — being without becoming.

The two-interval world. Now give the bulk a second interval in place of the circle. No direction supports holonomy; no quantity is quantized; nothing is protected. Walk through what is lost. There is no charge that cannot leak, so there are no stable atoms; no phase that returns, so no interference, no spectra, no clocks; no class structure, so no two electrons are the same and chemistry has no table; no alphabet, so even if a selection occurred there is nothing exact in which to write the outcome. Becoming proceeds — one-way, relentlessly — but converges on nothing and retains

nothing: every deposit erodes, because the vault was never topological. A two-interval world is a river with no banks — becoming without being.

The census, once more. One of each, and both defects cancel against the other’s virtue: the circle gives the river its banks (records deposited into protected classes), and the interval gives the archive its history (a direction along which the books are written). The reader should notice what kind of argument this is: not a fit to data, but a transcendental-style necessity claim run inside physics — *any* world with observers, records, and chemistry needs the census $1 + 1$, and the constitution’s theorems (Arisaka, 2026, A2-GG6) are the formal version of exactly this count. The anatomy is not one design choice among many; it is the shape of the possibility of worlds like ours.

18 Determinism: symmetry breaking as symmetry reading

The anatomy’s deepest single yield — developed at full length in GG-W1-Symmetry (Arisaka, 2026, W1-Symmetry) and carried here because Parts III–VI lean on it — is that symmetry breaking in this geometry is *deterministic*: the same outcome in every region, every time, with no lottery anywhere. Three mechanisms close every door through which randomness enters the standard accounts, and each lives on a named fiber structure:

1. **The dial, not the hat.** The vacuum manifold of the compact sector is not a continuous circle of equivalent minima (the Mexican hat’s rim) but a *quantized dial*: the Wilson-line vacua sit at discrete ledger-rational angles, and the scan has a unique winner. There is no continuum from which to draw a random choice — the circle’s alphabet is discrete.
2. **The Morse-unique floor, and the one condition it carries.** On each stratum the GFF landscape has a deepest minimum — the GGA — and the descent halts there, by the Morse analysis of Arisaka (2026, A6-GRIP). The condition belongs in the same breath as the mechanism. That the cascade *stops* is established; that it stops in *one* place is not. The upgrade from *a* attractor to *the* attractor is Frankel’s theorem with Atiyah’s extension (Frankel, 1959; Atiyah, 1982): on an *admissible* stratum — compact, connected, Kähler, the landscape a moment-map component of a torus action with isolated critical points — every Morse index is even, the landscape is a perfect Morse function, and the number of floors is the zeroth Betti number, one. Off such strata the uniqueness is open, and the companion review registers it so (Arisaka, 2026, W1-Symmetry). An earlier statement of this bullet named strict Morse positivity as the condition; it is not — two distinct minima satisfy $a^+ - a^- > 0$ — and it is a family-counting device in Arisaka (2026, A6-GRIP), where perfection and connectedness carry the uniqueness clause. What “the landscape” is has its own levels, and the bullet should say them once: that *some* function descends along every orbit is Conley’s theorem for any compact state space (Conley, 1978); that it is the relative entropy to the stationary state is Lindblad’s and Spohn’s for any open quantum dynamics (Lindblad, 1975; Spohn, 1978); that on a stratum it has the shape just described is Frankel–Atiyah; and that on the family stratum it is the boundary dilatation charge is the runtime paper’s own identification, derived there from its

transport proposition. The cascade is known to stop; that it stops in one place is conditional, and the condition is admissibility. This paper carries the floor at that grade everywhere it uses it, and §47 lists it among the named joints. The bullet is kept because a degeneracy of floors would have to be exhibited rather than merely feared — and if one is exhibited on an admissible stratum, where Frankel–Atiyah forbids it, this reading of determinism dies with it (§38).

3. **The semigroup cannot re-choose.** Whatever the descent deposits is final: the interval has no inverse transport, so no fluctuation can undo a selection and try again.

Together: nothing random survives at the level of which world is selected. Curie’s principle — that an asymmetric outcome needs an asymmetric cause — is dissolved rather than violated: the dynamics is symmetric, the *arithmetic* is not, and the outcome reads the arithmetic. The image the cohort has adopted: the circle is a *tape* on which the constitution’s integers are pressed like a groove; the interval is the *read head*, drawn across the tape once, at a rate the geometry fixes; and what looks like symmetry *breaking* — the cascade of choices from the GUT edge to the electroweak vacuum to the flavor textures — is symmetry *reading*: the one-way playback of a groove that was never symmetric. Something emerges from nothing deterministically and inevitably, because the nothing was a tape with a groove in it, and the player only runs forward — a sentence that carries three grades, and the bullet above says which: a theorem on the admissible strata of matter, a conjecture on the Wilson-line stratum, where a periodic potential may carry two floors of equal depth, and a wager above matter, where the landscapes of chemistry and cognition are the capstone’s to identify. And the triad is the seam shape this paper keeps meeting: the alternatives are the circle’s, the once-only execution is the interval’s, the record is circle-kept — symmetry breaking stands to the groove exactly as the write of Problem 1 stands to the record.

19 The gearbox: where the fibers multiply

The two fibers are opposite in kind, but they are fibers of one bulk, and there is a recurring grammatical form wherever they meet: a *circle integer dividing or correcting an interval scale*. The lock scale is the template,

$$M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} = 3.849 \text{ TeV}, \quad (15)$$

an interval-side depth (e^{-K} , thirty-five e-folds of descent) whose exponent is a circle-side integer ($K = 35$, a ledger member). The Kaxion’s decay constant repeats the form, $f_K = f_{\text{bulk}}/\Xi_{\text{cap}}$ with $\Xi_{\text{cap}} = K + N + L = 43$ (benchmark; the one open integer of Arisaka, 2026, C1-Kaxion); the dark-energy seesaw squares it, $m_\Lambda = M_{\text{lock}}^2/M_{\text{Pl,red}}$ (Problem 7); and the codebook reads the same grammar across the quark floors — a compact-angle winding (the circle’s label) multiplying a radial overlap (the interval’s address) (Arisaka, 2026, A9-SM). The general lesson, used repeatedly below: when a formula mixes an exact integer with a continuous scale, the integer is the circle speaking and the scale is the interval — and when a residual uncertainty survives in the cohort, it sits precisely at such a seam, because the seam is the only place a number can still move.

20 The map, restated

Part I has already tabulated the sixteen problems and their locations; with the anatomy now built, the map can be restated in one sentence per category. *The Standard Model* (Part III): quantum mechanics' two halves, the three interactions' three characters, gauge invariance and renormalization as the two fibers made law, and the parameter count as labels wearing addresses. *Cosmology* (Part IV): the launch, the hierarchy-as-depth, the dark trio, and the three horizons. *The foundation of particle physics* (Part V): the discrete symmetries, the antiparticle and the excess, and the guarded proton. *The foundation of the cosmos* (Part VI): time, the three currencies, the landscape question, and the black hole. Part VII is the Discussion — significance, comparisons, the honest-status ledger, and the consolidated falsifier table — and Part VIII concludes in the author's own voice.

21 Physics intuition: five images to keep

Formal statements travel farther with handles. Five images recur through the cohort and through this paper; the reader is invited to adopt them, with the caution that each is an image of a theorem, not a substitute for one.

The tape and the read head. The circle is a tape on which the constitution's integers are pressed as a groove; the interval is the read head, drawn across once at a rate the geometry fixes. Symmetry breaking is the playback (§18). The image earns its keep because it locates the determinism: grooves play back the same in every player.

The archive and the river. The two counterfactual worlds (§17): all circle is an archive with no history; all interval is a river with no banks. Our world is a river running past an archive, depositing into it — and the deposits are the only bridge: events become records, records are kept as classes.

The dial, not the hat. The compact sector's vacua are positions on a notched dial, not points on a hat's smooth rim. Where a hat invites a lottery, a dial invites a scan — and a scan has a winner (§18).

The label wearing an address. Every particle, every parameter: what it *is* lives on the circle, exact; what it *has* — mass, scale, epoch — lives on the interval, placed. When a formula mixes an integer with an exponential of K , read the integer as the label and the exponential as the address (§19).

The toll and the ledger. Whatever crosses the descent pays — in suppression factors that are exponentials of depth — and whatever is banked on the circle is kept without maintenance — integers pay no storage fee. The matter excess is a paid toll (Problem 11); the proton is a fee-free deposit (Problem 12); dark energy is the final invoice (Problem 7).

22 Reading conventions: the grade vocabulary

Because every claim below is carried at its parent’s grade, the vocabulary is fixed here once. *Derived*: follows from the declared axioms with no further input; the reader can audit the chain. *Derived-conditional*: derived modulo named lemmas or constructions, each stated where used (the conditions are part of the claim). *Named input*: a quantity taken from measurement or assigned by a declared choice, counted and listed — never smuggled. *Postulated*: a step asserted with its motivation but without derivation, flagged as such (the $K/2$ exponent of Problem 11 is this paper’s chief example). *Flagged*: a numerical observation recorded under the cohort’s numerology discipline — reproducible arithmetic, no mechanism yet, never used as support (the $4K/8K$ family). The discipline’s point is asymmetry: grades may be cited downward (a derived claim may be used anywhere) but never upward (nothing leans on a flag). A synthesis paper lives or dies by keeping this straight, and the reader is invited to police it.

23 The deployment: one sentence, twenty-two papers

The anatomy of this Part is not a proposal awaiting adoption; it is the reading the cohort was already written in, recovered and stated once. In the campaign that preceded this white paper, the exact statement was carried into every paper of the deployment — twenty-two in all — and in each case the entry point is the paper’s own central topic, not an appended commentary. Figure 6 draws the cohort whole, and Table 5 records where the statement enters each of its papers. What the two together show is that a reading which had to be forced would have needed a different door in each house, and this one used the front door every time; what it cannot show is whether that is a fact about the geometry or a fact about the author, and §24 is where the paper says so in its own voice.

23.1 The cohort at a glance

The cohort is not a series in the ordinary sense — not a first, second and third instalment to be taken in order. It is a dependency graph, and Figure 6 is that graph drawn once. The same figure is carried by every paper that has one, so a reader who has met it elsewhere may go straight on; a reader meeting it here should know four things about how it is drawn.

The spine. A single column descends from the constitutional root GG-A1-Constitution (violet), which supplies the four axioms and seven postulates, through the GG6 Trio that realizes the bulk geometry (GG-A2-GG6, GG-A3-BI6, GG-A4-Euclid), the boundary law GG-A5-GDOS, the GDOS Trio pillars GG-A6-GRIP and GG-A7-Qi4, the 4D-Physics Trio GG-A8-QM, GG-A9-SM and GG-A10-Cosmos, to the closing capstone GG-A11-Origin. Solid arrows mark axiom-forced descent, and where the driving axiom or postulate is most illustrative the arrow carries its name. Nothing on the spine is decorative: remove a box and everything below it loses its warrant.

The two framed rows. Beneath the spine sit the seven short papers that can be wrong in public — the Predictions Branch (cyan) and the Cosmology & Astrophysics Branch (teal). They are framed apart from the spine because their job is different: each is a falsifier of a specific upstream theorem, and each states a number or a bound that an experiment can retire. The internal arrows along the

Predictions row are results being handed along it, not axioms descending.

The two flanking columns. Two columns of two stand either side of the spine, and they do opposite jobs. On the left the Foundations Branch (violet) *feeds* it: GG-P4-Real manufactures the i that GG-A8-QM consumes, and GG-P5-CPT sits at the GG-A9-SM–GG-A10-Cosmos interface, taking ledger phases and returning the matter-excess chain. On the right the White-Paper Branch (brown) *reads* it. Every edge into the right-hand column is dashed, which in this figure’s grammar means the deployment of a result already derived elsewhere — and that, drawn, is the whole status claim of the two white papers.

Where this paper is. GG-W2-Holonomy is the lower box of the right-hand column. The single dashed feed drawn into it, from GG-A10-Cosmos, names its heaviest source and not its only one: the honest statement is that this paper reads all of the spine and both framed rows, and the figure would be unreadable if every such edge were drawn. The solid arrow above it, from GG-W1-Symmetry, is the one structural dependency between the two syntheses — the century-long arc ends where protection stops coming from symmetry and starts coming from topology, and that is where this paper begins.

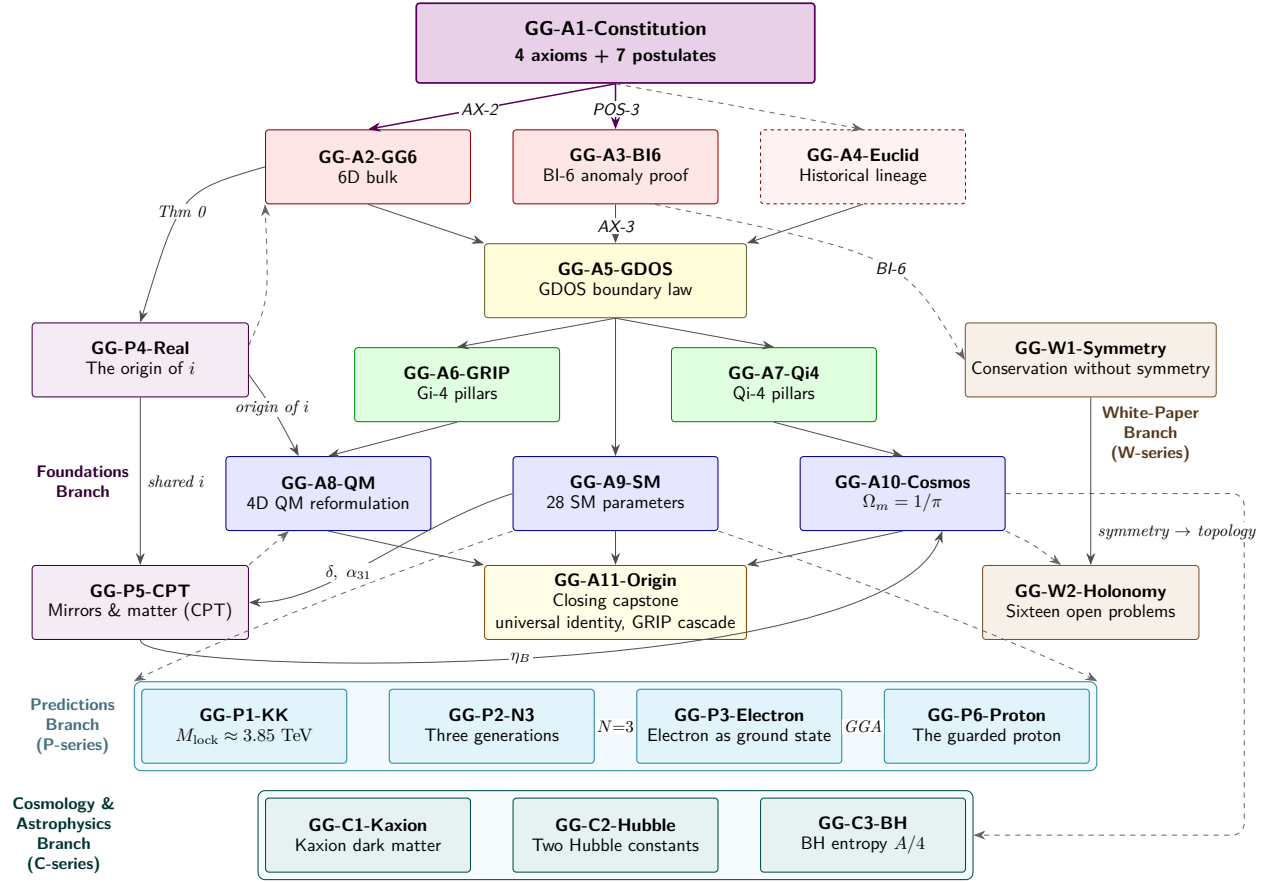


Figure 6: The twenty-two-paper cohort map of GG-Theory. The constitutional root GG-A1-Constitution (violet, top) supplies the four axioms and seven postulates from which the rest of the cohort descends: the GG6 Trio (GG-A2-GG6, GG-A3-BI6, GG-A4-Euclid, red) realizes the bulk geometry; GG-A5-GDOS (yellow) the boundary law; the GDOS Trio pillars (GG-A6-GRIP, GG-A7-Qi4, green) the geometric and quantum-information runtime; the 4D-Physics Trio (GG-A8-QM, GG-A9-SM, GG-A10-Cosmos, blue) the textbook readouts; and the closing capstone GG-A11-Origin (gold) the quarks-to-consciousness identity cascade. Two framed branches carry the phenomenology — the **Predictions Branch** (cyan), whose four papers hand their results along the row by the internal arrows (GG-P2-N3’s $N_g=3$ into GG-P3-Electron, and that paper’s ground-attractor method, GGA, on into GG-P6-Proton), and the **Cosmology & Astrophysics Branch** (teal). The spine is flanked by two columns of two, which do opposite jobs. On the left the **Foundations Branch** (violet) feeds it: GG-P4-Real, fed by GG-A2-GG6’s Theorem 0 arena, manufactures the i that GG-A8-QM consumes, and GG-P5-CPT is the GG-A9-SM–GG-A10-Cosmos interface, fed by the ledger phases and feeding the η_B chain across the width of the map, with the shared- i edge descending solid between them. On the right the **White-Paper Branch** (brown) reads it: GG-W1-Symmetry walks the century from Noether to Hopkins–Singer, and GG-W2-Holonomy dissects the structure that arc arrives at — protection by topology rather than by symmetry — across sixteen open problems. The white papers derive nothing new, carrying every result at its parent’s declared grade; the single dashed feed drawn into each names its heaviest source, not its only one. *Reading conventions:* solid arrows mark axiom-forced descent and carry an edge label naming the driving axiom or postulate where most illustrative; dashed arrows mark the deployment of derived results, or historical links inherited without being constitutionally forced.

23.2 Where the anatomy enters each paper

Table 5: The campaign map: where the two-fiber anatomy enters each cohort paper, always through its central topic. There are twenty-two rows, one for every paper in the cohort, and each names the point at which the anatomy enters that paper’s own argument rather than a general resemblance — from the constitutional minimum in A1 to the consolidation in the present paper.

Paper	Entry point
A1-Constitution	the pair as the constitutional minimum: one fiber of each kind, or no world that is and becomes
A2-GG6	the pair read together: what the four geometric pictures jointly buy
A3-BI6	why the anomaly ledger cannot run: inflow as circle-side bookkeeping
A4-Euclid	the five constants sorted: $\hbar$ the circle’s, G_N the interval’s
A5-GDOS	the two currencies: the first law the circle’s ledger, the second the interval’s
A6-GRIP	the engine’s strokes: GRIP-In the circle’s, GRIP-Out the interval’s
A7-Qi4	memory on the circle, erasure on the interval: Landauer as the toll
A8-QM	the measurement arrow: the write is interval-side, the record circle-kept
A9-SM	the codebook sorted: every parameter a label wearing an address
A10-Cosmos	the chronology, and the trio: rolling, ringing, rest
A11-Origin	the cascade and the origin: seventeen events, one reading
C1-Kaxion	the third portrait: matter of the circle, occupancy of the interval
C2-Hubble	the rate: how fast does the fiber that forgets forget
C3-BH	the paradox as a billing error: one fiber charged for the other’s job
P1-KK	the discovery as a double reading: identity from the circle, address from the interval
P2-N3	the method, and the seam: a count the circle protects, a bound the interval prices; and in its Appendix H, what the circle quantizes is what the interval delivers
P3-Electron	the first portrait: a holonomy class wearing a mass
P4-Real	the notation: the i on loan from the circle; records real by the interval
P5-CPT	the birth and the time: the alphabet, the toll, the tick and the arrow
P6-Proton	the double guard: the triangle that closes, the ledgers that keep
W1-Symmetry	the capstone: symmetry breaking as symmetry reading
W2-Holonomy	the present paper: the consolidation, where the readings above are rewritten once, in one voice, across sixteen problems

Two lessons from the map, before the applications begin. *First*, the anatomy is a synthesis discipline, not a metaphor bank: in every deployment the sorting had to reproduce the paper’s established results exactly, at their established grades, and it did — across twenty-two papers, no clause of the campaign required a value change, a retraction, or a promotion anywhere in the cohort. Whether that makes it an anatomy or a well-chosen vocabulary is a fair question, and §24 and Part X both take it up. *Second*, the map explains this paper’s method: each Part below is the consolidation of several entries of Table 5, rewritten once, in one voice, for a reader who should not have to assemble the story from twenty-two places.

23.3 Where to go next

A map is only useful if it is also a door. What follows is for the reader who has come this far, has decided the sentence is worth an afternoon, and would like to know which paper to open next. The answer depends on what brought him here, so here are seven routes. Each names its papers, says what the reader gets, and — because this is a cohort that prints its own kill conditions — says what it costs.

If the first question is what is actually assumed. Start at GG-A1-Constitution ([Arisaka, 2026, A1-Constitution](#)): four axioms, seven postulates, and the warrant for everything else, gathered in one document with the whole inheritance drawn as Figure 3 of that paper — the same plate printed above. Then GG-A2-GG6 ([Arisaka, 2026, A2-GG6](#)), which builds the arena the axioms describe and shows what the four geometric pictures jointly buy. A reader who would rather arrive by the classical route than the axiomatic one should take GG-A4-Euclid ([Arisaka, 2026, A4-Euclid](#)) instead, which walks in from Euclid and rebuilds the constants on the way.

If the interest is the mathematics. GG-A3-BI6 ([Arisaka, 2026, A3-BI6](#)) is the hardest paper of the cohort and the most load-bearing: anomaly freedom of the modified Bianchi identity in six dimensions, which is what licenses the ledger everything downstream spends. It is also where the century-long arc of GG-W1-Symmetry ends, so the two can be read together. Its natural companion is GG-P4-Real ([Arisaka, 2026, P4-Real](#)), the paper that says where the i of quantum mechanics comes from and why records come out real — the question this paper’s Problem 9 answers in one sentence and that paper answers in a hundred pages.

If the interest is the machinery this paper leans on. GG-A5-GDOS ([Arisaka, 2026, A5-GDOS](#)) is the single paper the present one uses most: the boundary law, and the open-system turn on which the whole two-fiber reading depends. GG-A6-GRIP ([Arisaka, 2026, A6-GRIP](#)) is the geometric runtime, and its cascade is the engine of §12.2 above read on the two fibers: GRIP-In the circle’s stroke, GRIP-Out the interval’s. GG-A7-Qi4 ([Arisaka, 2026, A7-Qi4](#)) is the quantum-information one, where memory and erasure are priced and Landauer’s bound becomes the toll. A reader who found the circle and the interval persuasive but wants to see them made to work should read these three in order.

If the interest is seeing the textbooks come out. GG-A8-QM ([Arisaka, 2026, A8-QM](#)) derives quantum mechanics as the projection of the bulk on the boundary, and is careful to say which part of the Born rule is closed and which is not. GG-A9-SM ([Arisaka, 2026, A9-SM](#)) sorts the Standard Model’s parameters into observations of one geometry. GG-A10-Cosmos ([Arisaka, 2026, A10-Cosmos](#)) does the same for the cosmic inventory and the chronology. These are the three papers where the program is at its most checkable by hand: the numbers are there, and so are the derivations that produced them.

If the interest is the long view. GG-A11-Origin ([Arisaka, 2026, A11-Origin](#)) runs the cascade from quarks to consciousness and asks why the layers are the layers. It is the most ambitious paper of the cohort and the most exposed, and it says so in its own front matter; a skeptical reader may prefer to arrive there last rather than first, which is also the order the cohort intends.

If the interest is something to shoot at. The seven short papers of the two framed rows exist to be retired by measurement. GG-P1-KK ([Arisaka, 2026, P1-KK](#)) puts a lock cluster near 3.85 TeV, which is a standing falsifier at the LHC. GG-C1-Kaxion ([Arisaka, 2026, C1-Kaxion](#)) puts cold dark matter at $8.1\,\mu\text{eV}$, a haloscope band a running experiment can close. GG-C2-Hubble ([Arisaka, 2026, C2-Hubble](#)) reads the two Hubble constants as the two ends of one corridor rather than as a discrepancy to be split. GG-P2-N3 ([Arisaka, 2026, P2-N3](#)) derives the generation count, and its Appendix H is the place to go for the seam this paper describes in Problem 2. GG-P3-Electron ([Arisaka, 2026, P3-Electron](#)) and GG-P6-Proton ([Arisaka, 2026, P6-Proton](#)) take the electron and the proton as ground states of their strata — and a single verified proton decay ends the second of them outright. GG-C3-BH ([Arisaka, 2026, C3-BH](#)) recovers the Bekenstein–Hawking entropy exactly and reads the paradox as a billing error. One paper belongs with these without standing in the rows: GG-P5-CPT ([Arisaka, 2026, P5-CPT](#)), which sits on the spine’s left flank and is the widest of the exposed papers, taking the mirrors of matter, the arrow of time and the matter excess together.

If the interest is the history rather than the anatomy. GG-W1-Symmetry ([Arisaka, 2026, W1-Symmetry](#)) is this paper’s sibling and its opposite in method. Where the present paper takes one statement and cuts across sixteen problems at once, that one takes seven results — Noether’s two theorems, the Bianchi identity, its quantized failure, Green–Schwarz, Hopkins–Singer — in the order they were found, and follows a single belief until it gives way. A reader who wants to know how physics arrived at protection by topology should read it first; a reader who wants to know what that protection buys is already in the right place.

How to read any of them cold. Every paper of the cohort opens with an abstract, an executive summary and a preface written for someone who has read none of the others, and closes with a falsifier table and a Part of common objections with responses. The fastest honest route into any of them is therefore not the front: it is the abstract, then the falsifier table, then a decision about whether the rest is worth the afternoon. A reader who wants to know what a paper is risking before he learns what it is claiming has exactly the order the cohort prefers, and this paper would rather be read that way than politely.

24 The honest record: where this kind of reasoning has misled physics

Table 5 is the strongest thing this Part has to offer short of an experiment, and it is also the most selection-prone. An organizing language in physics ordinarily earns its keep by suggesting modifications; this one earned its keep by failing to require any — which is either a description

fitting a thing that was already there, or an author fitting a vocabulary to his own work. The falsifier table of §48 exists because that difference is not settled from an armchair. But something is owed before the reader gets there, and it is not a falsifier. It is the other column: the record of what *this style of reasoning* has cost physics when it was wrong, and the list of questions this particular instrument is bad at. A paper that prints its own kill conditions and not its own cautionary history has printed the cheaper half.

Three episodes, none of them flattering

Weyl, 1918: the scale direction, gauged. The first attempt to unify electromagnetism with gravity made the local scale of length a gauge freedom (Weyl, 1918). It was beautiful, it was geometrically natural, and it was dead within a year: if length is locally gauged, a clock’s rate depends on the path it has traveled, so two atoms brought together after different histories would show different spectral lines. They do not. The objection was Einstein’s and it was fatal, and the repair that eventually worked was not a refinement but a *fiber swap* — from a direction whose value is physical to one whose value is not, which is the modern gauge principle (Weyl, 1929).

This paper should be the last to tell that story lightly, because the fifth dimension of Eq. (1) *is* the scale direction. The difference is precise and the reader is entitled to weigh it: Weyl gave the scale direction gauge-invariant content, and here it has none, which is exactly what premise (T) says and exactly why the interval forgets. So the anatomy is on the right side of Weyl’s failure. But it is on the right side of it by one clause, and Weyl’s program is the closest historical precedent to this paper’s central object. Anyone who wants a reason for skepticism about a geometrically natural claim concerning the fifth dimension has a century-old one, and it is a good one.

Kaluza–Klein, 1926 to the 1980s: compactness expected to fix the content. For sixty years a great deal of work proceeded on the expectation that compactifying extra dimensions would, by itself, determine the low-energy spectrum: choose the manifold, turn the crank, read off the particles. It did not, and there is no Kaluza–Klein poverty theorem to this day — the content depends on choices the compactness does not make. The lesson bears directly on how this paper should be read. “The circle is compact, therefore its content is quantized” is premise (T) and is true. “Therefore its content is *determined*” does not follow and is not claimed anywhere here: the ledger $(M, N, L; J, K)$ comes from Step A’s anomaly audit, not from the circle being closed. A reader who runs the two together has made the mistake the field spent sixty years making, and the paper’s own compressions must not invite it — which is why §44 states that the numbers are sorted by the anatomy and produced by the applications.

No elementary scalar, 1979 to 2012. A generation of model-building rested on a structural instinct: a fundamental scalar cannot exist, because nothing protects its mass. The instinct was articulated by the best people in the field (Susskind, 1979; ‘t Hooft, 1980), it generated technicolor and the composite-Higgs program, and it was falsified by a scalar at 125 GeV that behaves, so far, exactly as an elementary one (ATLAS Collaboration, 2012; CMS Collaboration, 2012). This episode costs the present framework something specific and the honest register requires naming it. This paper’s own account of the electroweak scale (§27.8) is a structural argument for why an elementary-looking scalar is *allowed* — its vacuum value is placed by a holonomy that no local counterterm can move,

rather than held in place by a symmetry. That is the same genre of argument as the one that failed, run in the opposite direction. The generalization worth carrying is that structural claims about what nature *cannot* do have a markedly worse record than structural claims about what it *must*, and this paper makes claims of both kinds.

The instrument’s own besetting temptation

Every instrument has a characteristic way of going wrong, and this one’s is over-attribution: writing that a result follows from *holonomy requires closed loops, and an interval has none* when it follows from that sentence together with something else that has not been said. The temptation is strong precisely because the sentence is true and elementary, so anything placed next to it inherits its air of inevitability. Two live instances are named in this paper rather than left for a critic.

The first is the semigroup. It is natural to write that the interval’s transports lack inverses *because* the interval does not close. They do lack inverses, but not for that reason: parallel transport along a path in I_r is invertible, and Appendix 63 gauges the interval’s connection away entirely. The one-wayness is the coarse-graining flow’s, and it belongs to premise (D). §13 now states the two premises apart for this reason alone.

The second is the drain. It is natural to write that the interval supplies the continuum of final states that irreversibility requires, while the compact circle cannot. But $I_r = [0, K]$ is a finite segment with boundary; its spectrum is discrete under any self-adjoint boundary condition, and its level spacing is the largest in the whole framework, since it is the same spacing that puts the lock cluster at 3.849 TeV. Appendix 64.3 says so in place, and rests the fiber assignment on the composition law instead, where it belongs.

Neither correction changes a number, and that is the point worth making: both sentences *felt* like consequences of the founding statement, and neither was one. A reader who finds a third such sentence has found a real defect, and the author would like to be told which paragraph.

What the anatomy cannot see

The instrument sorts by two properties, exactness and one-wayness. Its reach is bounded by that, and the boundary is not a matter of the work being unfinished — it is what the instrument is.

Where a question’s content is neither exact nor one-way, the anatomy supplies a filing category and no dynamics. It has nothing to say about why the deuteron binds, or about the detailed shape of a hadron, or about how the first galaxies assembled, or about the ordering of masses *within* a generation once the codebook’s alphabet is granted. A reader who asks the anatomy why nuclear matter saturates will receive an answer that is correct — the binding is an interval-side address, priced by the descent — and useless, because correct filing is not a calculation. The cohort’s papers do the calculations where they exist; the anatomy says which drawer, and a drawer is not a mechanism.

There is a second and sharper limit. The sorting is only as good as the assignment, and in at least one place the assignment is a naming convention rather than a derived fact: $K = 35$ is a circle-side integer by §19’s rule, and it is also the *length* of the interval, $I_r = [0, K]$. The gearbox reading is consistent and is stated before it is used, but nothing in the geometry distinguishes “the circle’s

integer, used as the interval’s length” from “the interval has a quantized extent.” Since the contrast between the exact-and-protected and the flowing-and-priced is the engine of the whole paper, the reader should know that the interval’s one exact attribute is its extent, that this is a boundary condition rather than a holonomy, and that the paper’s most important single number sits on that seam.

The generalization, stated against interest

Reading a century of these episodes together, the honest generalization is not that geometric reasoning is unreliable. It is narrower and less comfortable: *topology read off a structure the physics forced has a good record; topology imposed on a structure because the topology was attractive has a poor one.* Weyl’s scale gauge was imposed. The Kaluza–Klein poverty hope was imposed. The no-elementary-scalar instinct was imposed. Noether’s theorem, the Aharonov–Bohm phase, the Wilson loop and the index theorems were read off.

This paper’s entire defense is that its bulk belongs to the first category — that $\mathcal{M}_6 = \mathcal{M}_4 \times I_r \times S_\theta^1$ is forced by an axiom set declared in Step A, before any of the sorting in Parts III–VI was attempted, and that the sorting was therefore constrained rather than free. That defense is a claim about the order in which the work was done, and a reader is entitled to be unmoved by it. A reader who is unmoved should read Parts III–VI as a vocabulary rather than an anatomy, should say so plainly, and will find that the paper’s numbers are unaffected either way — because they were never the anatomy’s, and §44 says whose they are.

Part II in one paragraph, and what comes next

The instrument is now on the bench. One arena, $\mathcal{M}_6 = \mathcal{M}_4 \times I_r \times S_\theta^1$, forced by the constitution rather than chosen; one compact fiber whose transports form a group, so that everything written on it is a holonomy — quantized, gauge-protected, with nowhere to move; one open fiber whose transports form a semigroup, so that everything written on it composes forward and never inverts. One of each, because two circles would conserve everything and decide nothing, and two intervals the reverse. Five integers $(M, N, L; J, K) = (1, 3, 5; 7, 35)$ carrying the circle’s arithmetic, depths along the interval carrying the rest, and a grade vocabulary — derived, derived-conditional, named input, postulated, flagged — that every claim after this page wears in public.

Everything that follows is that one instrument, applied sixteen times and never modified. Part III applies it first to the theory we trust most and understand least: the Standard Model, which predicts to eleven decimal places, needs two dynamics to describe one measurement, cannot say where its own gauge principle comes from, and asks the experimenter for twenty-eight numbers it cannot compute.

Part III

The Standard Model

Problems 1–4: Measurement, the Four Interactions, Gauge Invariance and Renormalization, and the Parameter Count

The four problems of this Part are the Standard Model’s deepest embarrassments: its measurement rule is postulated, its three gauge forces are inexplicably unlike, its defining local symmetry is (by Noether’s own second theorem) a redundancy, and its parameter list is long enough to have launched a landscape. All four are developed below; Problem 2 carries the fullest quantitative apparatus.

25 Problem 1. The Measurement Problem of Quantum Mechanics

25.1 The problem, in its sharpest form

Quantum mechanics is two theories wearing one name. The first is a jewel: amplitudes evolve deterministically, reversibly, linearly — the Schrödinger dynamics, tested to eleven decimal places. The second is a rule of thumb: when a “measurement” happens, the amplitudes collapse to one outcome, with probabilities given by the Born rule, irreversibly. The scandal is not that the second rule fails — it never fails — but that nobody can say when it applies. What counts as a measurement? A photographic grain? A Geiger click? A graduate student? The theory’s own equations never collapse anything: a detector coupled to a superposed atom becomes, by the first dynamics, a superposed detector. Yet no one has ever seen a superposed detector. For a century the escape routes have multiplied — consciousness, many worlds, spontaneous collapse, hidden variables — and the fact that all of them still have serious advocates is the measure of the problem: the experiments cannot yet tell them apart, and the theory cannot referee its own foundations.

Put the question in its sharpest form: *why does a reversible theory produce irreversible events?* Any answer must explain three things at once: why outcomes are single (one grain darkens), why records are permanent (it stays darkened), and why the statistics are exactly Born’s (the squared amplitude, never anything else).

The scandal is sharpest when the two rules are written side by side. Between measurements, the state $|\psi\rangle$ obeys the Schrödinger equation,

$$i\hbar \frac{\partial}{\partial t} |\psi\rangle = H |\psi\rangle, \quad (16)$$

where H is the Hamiltonian — the energy operator, the generator of time evolution — and $\hbar$ converts energy to phase rate. This rule is linear, deterministic, and reversible: given the state now, the state at any earlier or later time is fixed, and the evolution can be run backward by $H \rightarrow -H$. At a measurement of an observable with projectors P_k (the operator asking “is the outcome k ?”),

the state instead obeys the Lüders update,

$$|\psi\rangle \longrightarrow \frac{P_k |\psi\rangle}{\sqrt{p_k}} \quad \text{with probability} \quad p_k = \langle \psi | P_k | \psi \rangle, \quad (17)$$

which is nonlinear (the state is renormalized), stochastic (only the probabilities are fixed), and irreversible (the discarded branches cannot be recovered from the survivor). The intuition to hold: Eq. (16) is transport with an inverse and Eq. (17) is transport without one — a group rule and a semigroup rule, in the vocabulary of Eqs. (13)–(14) — and the measurement problem is that the textbook postulates both without saying which geometry supplies which.

25.2 The anatomy’s answer, in one paragraph

The two theories wearing one name are the two fibers wearing one bulk. The coherent half of quantum mechanics — superposition, interference, unitarity — is the circle’s: amplitudes are transport around S_θ^1 , their relative phases are the unread holonomy content, and the i in which they are written is on loan from the circle (Problem 9’s orientation calculus; Arisaka, 2026, P4-Real). The registering half is the interval’s: a measurement is a *write* along the fiber that composes only forward. Nothing needs to be added to the theory — no collapse postulate, no observer, no consciousness — because the boundary law GDOS already contains the write: OGGEF makes registration a projection that marginalizes the fiber coordinates, and it does so at every event, observed or not. “Collapse” is not a second dynamics; it is the runtime — the same one-way reading that runs cosmic history (Problem 13), met at laboratory scale. The books are reversible; the reading is not; and a measurement is a read.

In equation form, the answer is already on the table: the two rules of Eqs. (16)–(17) are the two terms of the GDOS master equation, Eq. (5) — the commutator $-\frac{i}{\hbar}[H, \rho]$ is Schrödinger evolution, the circle’s transported phase, and the dissipator $\mathcal{D}[\rho]$ is the write, the interval-side registration of which Eq. (17) is the completed limit. One equation, two fibers, no border to police: the “cut” is not a place but a process — wherever the dissipator’s registration outruns the commutator’s coherence, a record forms.

25.3 A measurement, walked through

Follow one silver atom through a Stern–Gerlach magnet, in the anatomy’s language. *Preparation* is circle-side: the atom’s spin state is a definite configuration of phase — holonomy data, coherent, carrying its superposition of up and down as a relative phase that nothing on the boundary has yet asked about. *Entanglement* is still circle-side: as the atom crosses the field gradient, its spin phase becomes correlated with its path — a bigger superposition, still coherent, still reversible in principle; if one recombined the beams with sufficient care, the interference would return, and in careful experiments (neutron interferometers, molecule interferometers) it demonstrably does. *Registration* is the new thing: the atom strikes the plate, and the correlation is written into the plate’s collective degrees of freedom — a one-way transfer, priced in the currency of Problem 14, that the runtime executes as an interval-side write. From that event forward there is no recombination, not because

the experimenter lacks skill but because the write went down the fiber with no inverse transport. *The record* then has the two properties every record has (Problem 13): it is *real* — written along the fiber that carries no phase, so there is nothing ambiguous left to interfere — and it is *permanent* — its content sits in quantities the circle protects.

The anatomy’s slogan for the whole sequence: *the circle carries the question; the interval writes the answer*. Before the write, phases; after the write, facts. The boundary between the two is not the size of the apparatus, nor the presence of a mind, but an event type — the one-way write — which is why a photographic grain suffices and a galaxy of coherent atoms does not.

Figure 7 draws the walk-through as the anatomy sees it: everything to the left of the screen is the circle’s business — both paths carried, a promise transported by a group — and the screen is the interval’s: one grain fires, one deposit, no inverse.

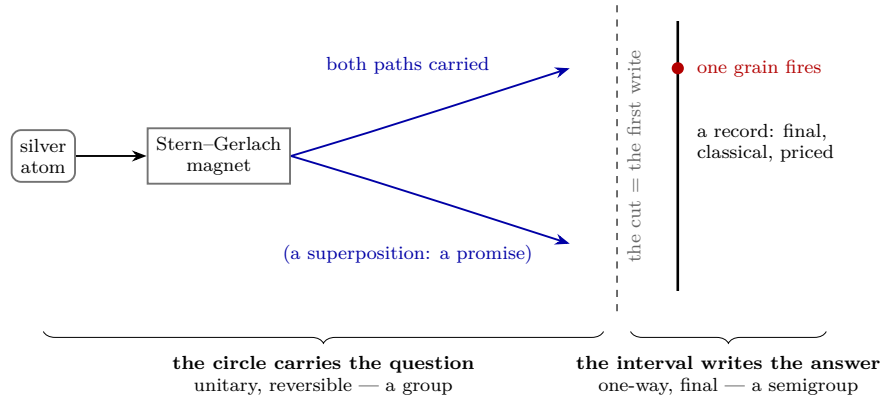


Figure 7: A measurement, sorted by fiber. Left of the cut, nothing has happened that cannot be undone: the two beams are the circle’s transported phase, a promise held open. At the screen the runtime’s projection acts — the one-way write — and one grain carries the deposit. The measurement problem was the demand that one algebra do both jobs; the anatomy hands each job to the fiber whose algebra fits it.

25.4 Why decoherence was almost the answer

The modern consensus rightly credits decoherence with half the solution: couple a superposed system to an environment, and the relative phases leak into unmonitored correlations at fantastic speed; interference becomes unobservable in practice; the reduced state looks classical. The anatomy honors this — decoherence is real, calculable, and confirmed — and locates precisely what it cannot do. Decoherence *delocalizes* phase; it does not *destroy* it. The global state remains a superposition; the outcome remains plural; “for all practical purposes” remains the load-bearing phrase. What finishes the job is what decoherence lacks: an actual one-way event. In GDOS the projection is not an approximation that improves with environment size — it is the boundary law itself, always on, and decoherence is its microscopic face while measurement is its record-forming face (Arisaka, 2026, A8-QM). The practical-purposes gap closes because the interval is not a practical purpose; it is a fiber.

Figure 8 shows the quantitative face of that “almost”: measured and computed decoherence rates across forty orders of magnitude.

25.5 Where the Born rule comes from

Probability is the deepest part of the scandal: even granting single outcomes, why the squared amplitude? The cohort’s answer is carried at a carefully stated level (Arisaka, 2026, A8-QM): the Born measure is not postulated but *produced* — the boundary law’s own dissipation relaxes the bulk’s configurational statistics toward the Born measure, monotonically, at a rate set by the port coupling; the standard quantum postulates (Hilbert space, unitary limit, Born form, Lüders conditioning) then follow as theorems of the relaxed runtime. The chain is closed at the relaxation level, with exactly one named analytic residue — the field-grade representation step — declared open, and the reader deserves the grade stated as plainly as the claim: *derived-conditional, one residue named*. What makes this more than an interpretation is that relaxation takes time, and time leaves fossils — the next section’s laboratory face.

25.6 The laboratory face

Three exposures make Problem 1 physics rather than philosophy. *First, the relic (F25)*. If Born statistics are relaxed into rather than axiomatic, then modes that left the cosmological horizon during inflation decoupled from the relaxing stream and froze whatever deviation remained. The largest observable scales should therefore carry a primordial-statistics deficit of computed form,

$$\xi(k) = 1 - A \left(\frac{k}{k_0} \right)^{-\gamma}, \quad (18)$$

where $\xi(k)$ measures how completely Born statistics hold at comoving wavenumber k ($\xi = 1$: exact Born), k_0 is the pivot scale set by the mode that left the horizon as relaxation completed, A is the residual deficit amplitude at the pivot, and $\gamma > 0$ is the relaxation exponent — both A and γ computable from the port coupling, with no new field and no dial. The intuition: modes that exited earliest sampled the least-relaxed statistics, so the deficit grows toward the largest scales as the power law records — a fossil of the pre-relaxation era, printed on the sky. A detected large-scale statistical anomaly incompatible with the computed form kills the relaxation account; exact Born statistics at all scales bounds the relaxation time from below. (The quantification of A and γ is a named cohort campaign.) *Second, the no-reversal bound*. The account forbids, at any scale, the resurrection of a registered outcome — not suppressed: forbidden. Every interference-revival experiment that pushes the macroscopic frontier (levitated spheres, mechanical resonators) is a test; a genuine revival of a registered record would falsify the write outright. *Third, the cost*. Every write is billed — the information-theoretic price of Problem 14 — so the account requires that no registration ever be free, an audit the information pillar carries (Arisaka, 2026, A7-Q14).

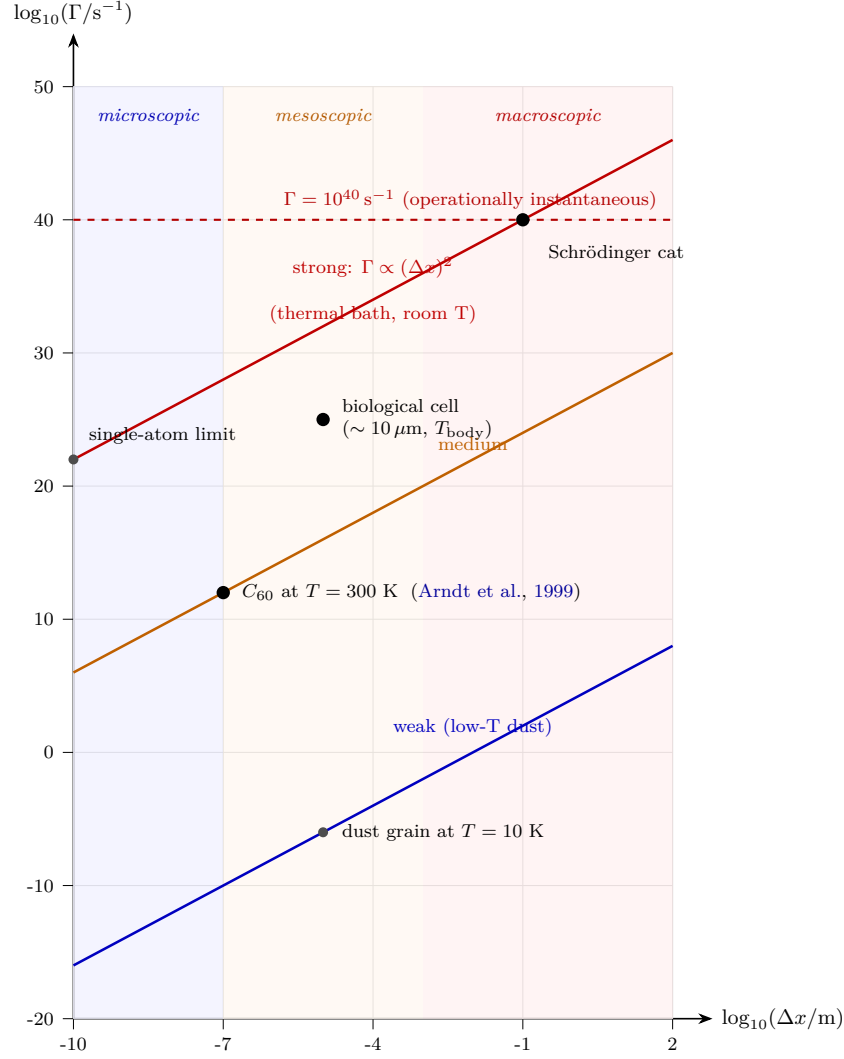


Figure 8: Decoherence is quantitative, not interpretive (reproduced from [Arisaka, 2026, A8-QM](#)). The off-diagonal damping rate Γ (vertical, powers of ten per second) against the position-separation Δx of the superposed alternatives (horizontal, meters), log-log, for standard environments. Γ scales as $(\Delta x)^2$ until saturation; a dust grain superposed over a micron decoheres in $\sim 10^{-24}$ s while an electron superposed over an Angstrom can hold coherence for seconds — forty orders of magnitude from one slope. On the anatomy this is the dissipator of Eq. (5) doing its bookkeeping: the rate at which the interval’s registration outruns the circle’s coherence, as a function of how loudly the superposition differs. What the slope does not do — and cannot do — is pick the grain’s final position: that is Eq. (17)’s job, and the distinction is this Problem’s entire content.

25.7 Schrödinger’s cat, dissected

The famous cat sharpens every clause. An unstable atom (circle-side: a phase configuration with two channels), a Geiger counter, a vial, a cat, a box. The textbook telling has the whole chain — atom, counter, vial, cat — in superposition until an observer opens the box, at which point reality decides. The anatomy’s telling has one question only: *where is the first one-way write?* And the answer is: at the counter — the avalanche discharge is a registration, an interval-side write billed and executed long before vial, cat, or observer. From that event the record exists; the cat’s fate is a fact of the world with the box still shut; and opening the box changes the observer’s knowledge, never the cat’s state. The thought experiment retains exactly one deep lesson, which the anatomy states without paradox: between the atom’s phases and the counter’s click there is a genuine transition of category — question to answer, circle to interval — and the line sits at an event type, not at a mind, a size, or a species. Nothing macroscopic was ever superposed, because nothing macroscopic gets assembled without a torrent of writes along the way; a “superposed detector” is not hard to build — it is a contradiction in the bookkeeping, like a spent coin still in the purse.

Figure 9 locates the write on the apparatus’s own timeline.

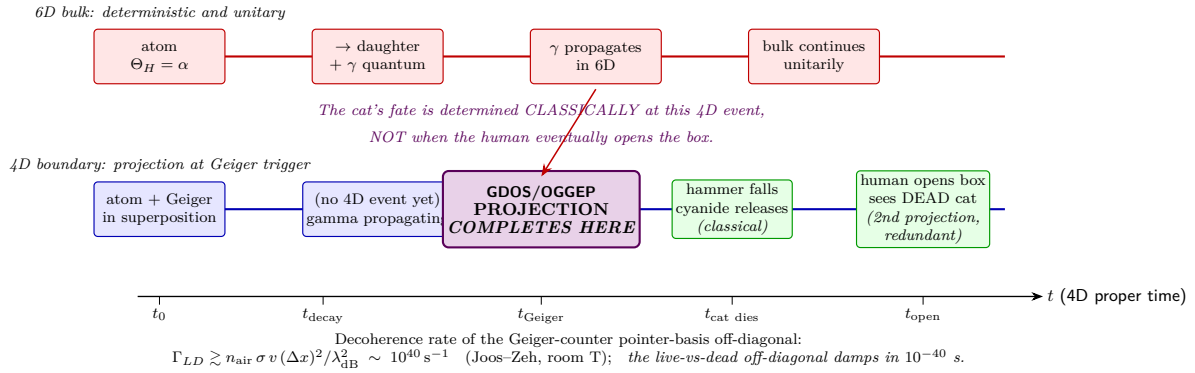


Figure 9: Where and when the cat’s fate is written (reproduced from Arisaka, 2026, A8-QM). The timeline of the apparatus: the nuclear superposition is coherent only until the Geiger counter’s avalanche — the first thermodynamically irreversible amplification — at which point the write of Eq. (17) has already happened, microseconds into the hour and meters from the cat. Everything downstream (hammer, vial, cat) is classical cause and effect among records. The paradox’s force always came from placing the write at the box’s opening; the dissipator’s timescales place it at the counter, and the superposed-cat state is never prepared at all.

25.8 Frequently asked

Doesn’t the write violate unitarity? The *books* stay unitary — the circle’s half is exact, and the global accounting (Problem 16 runs it across a black-hole horizon) always balances. What is not unitary is the *reading*: the boundary’s open-system evolution, which was never claimed to be reversible. The contradiction the textbooks fear arises only if one insists the reading be described by the books’ own dynamics — which is precisely the one-fiber assumption the anatomy retires.

Where exactly is the cut? At the first uncompensated one-way transfer — operationally, where the interference budget of Problem 14 is spent and cannot be repaid. This is a physical criterion, not a convention: it is why interferometers can revive coherence for molecules of thousands of atoms (no write yet) and why a single darkened grain cannot be undarkened by any unitary trick (write executed). The cut moves with experimental skill exactly as far as the write can be deferred, and not one step further.

Is the observer needed at all? No. The projection is always on — decoherence in the atmosphere, registration in a rock’s crystal defects, the cosmic writes of Problem 13 — and observers are late, local beneficiaries of a bookkeeping that has run since the launch. What observers contribute is what readers always contribute: nothing to the text, everything to the readership.

25.9 What the anatomy does not claim

Clean accounts of measurement attract enthusiastic misreadings, so the fences deserve a section. *No role for consciousness*: the write is an event type, executed identically in detectors, rocks, and interstellar dust; minds read ledgers, they do not close them. *No retrocausality*: delayed-choice experiments, correctly parsed, delay the *configuration of the question* (circle-side, revisable) and never a completed write; nothing in the anatomy reaches backward, because nothing can — the fiber that would carry the influence has no inverse transport. *No signaling from entanglement*: Bell correlations are real, and the anatomy reads them as class data — joint holonomy structure prepared once and carried apart, correlations without communication, exactly as Horizon 2 of Problem 8 reads cosmic sameness. What Bell’s theorem forbids is a local hidden story *on the boundary*; what it cannot forbid is bookkeeping in the fibers the boundary does not see — and no write anywhere in a Bell experiment transmits: the outcomes are registered locally, the correlation is discovered only when the records are brought together, along ordinary one-way channels. *No new constants*: unlike spontaneous-collapse models, the write’s rate is not a dial — it is the port coupling the boundary law already owns. The account’s entire novelty is an anatomy; its entire freedom is zero.

25.10 The interpretations, honored and placed

No polemic; each tradition holds a piece. *Copenhagen* was right that measurement is special and classical records are final — it lacked the geometry that says why, and so drew the quantum-classical cut as a moving convention rather than a fiber distinction. *Everett* was right that the unitary books never collapse — the circle’s truth — and the anatomy differs from many-worlds not by denying the reversible half but by asserting a physical second fiber on which reading happens once; branches, on this view, are bookkeeping of the unread, not inhabited worlds. *Spontaneous-collapse models* (GRW and kin) were right that irreversibility must be objective and dynamical — they built the one-way event by hand, with new constants; the anatomy gets it from a compulsory projection onto a fiber that has nothing to protect (premises (T) and (D) of §13), with no new constants at all. The economy is a real difference and the honest register requires saying what it is not: an always-on boundary projection is a structural postulate too, and its warrant here is only that the geometry forced it in Step B before the measurement problem was in view. *Decoherence theory* was right

about the mechanism’s face and, as above, half its content. The measurement problem, on the anatomy, was never a puzzle about minds or worlds: it was the two-fiber anatomy, encountered in a laboratory before it had been named — the oldest and most domestic instance of the circle that remembers meeting the interval that forgets.

Grade and kill, consolidated. The write and the record: theorems of the boundary law. The Born chain: derived-conditional, one residue named. Kill: the F25 relic off its computed form; a revived registered record; a free write. The detailed record discussion is §36.9; the cost audit is (Arisaka, 2026, A7-Qi4); the parent treatment end to end is (Arisaka, 2026, A8-QM).

Measurement was the circle and the interval caught in the act of doing two different jobs at one moment. The next Problem catches them doing two different jobs across the whole of physics: three of the four interactions are the circle registering, and the fourth is the interval acting.

26 Problem 2. A Distinct Difference between the Strong, Weak, and Electromagnetic Interactions — and Gravity

26.1 Three forces, three relations to the anatomy

The standard model presents its three gauge interactions as three instances of one principle, differing in group and coupling. The differences a student actually meets — one force is long-range and gentle, one confines absolutely, one is short-range, chiral, and alone changes what things *are* — arrive as outputs of detailed dynamics: a massless photon here, a running coupling there, a Higgs mechanism elsewhere. On the two-fiber anatomy the three differences are three *relations to the fibers*, visible before any dynamics is solved (Arisaka, 2026, A9-SM; Arisaka, 2026, P6-Proton; Arisaka, 2026, A6-GRIP):

*Electromagnetism is the circle’s open phase; the strong force is the circle’s closing figure;
the weak force is the interval’s agent.*

Table 6 is the Part in one view; the three sections that follow earn its rows.

One equation carries the entire sorting. Every interaction of the Standard Model enters through the same object, the covariant derivative acting on a matter field ψ :

$$D_\mu = \partial_\mu - ig_s G_\mu^a \frac{\lambda^a}{2} - ig W_\mu^i \frac{\tau^i}{2} - ig' B_\mu \frac{Y}{2}, \quad (19)$$

where G_μ^a ($a = 1..8$) are the gluon fields with coupling g_s and the λ^a the color matrices; W_μ^i ($i = 1..3$) the weak fields with coupling g and the τ^i the weak-isospin matrices; B_μ the hypercharge field with coupling g' and Y the hypercharge of ψ . The physical content: “interacting” *means* being transported — a particle feels a force exactly insofar as its phase is geared to a connection — and the three gearings differ only in which matrices multiply which fields. On the anatomy, Eq. (19) is the boundary registration of the single composite connection of Eq. (2): one object in the bulk, three gearings on the stage, and this Problem’s question — why the three behave so differently — becomes: what does each gearing’s structure look like when read on the two fibers?

Table 6: The three gauge interactions by fiber. Each row is established in the cited papers; the alignment is the anatomy’s. The seven rows compare the three interactions on range, on what each conserves, on chirality, on whether either can change identity, on the signature constant each carries — $\alpha^{-1}(0) = 2^J + N^2 = 137$, the triality $N = 3$, and $\sin^2 \theta_W = L^2/(4N^3) = 25/108$ — and on the fate of each symmetry. Only the weak interaction is chiral, and only the weak interaction changes flavor.

	Electromagnetic	Strong	Weak
Relation to anatomy	the circle’s unbroken phase	the circle’s closing triangle	the interval’s agent
Range	infinite: the phase is free to reach	zero at large distance: only closed books leave	short: the agent is massive, $\sim M_{\text{lock}}$ -fed scale
What it conserves	every winding: charge exact	triality inside closure; B via the ledger	least: it is the changer, not the keeper
Chirality	blind	blind	chiral: the descent selects a hand
Changes identity?	never	never	only force that does: flavor transitions
Signature constant	$\alpha^{-1}(0) = 2^J + N^2 = 137$	$N = 3$: the triality	$\sin^2 \theta_W = L^2/(4N^3) = 25/108$
Fate of its symmetry	unbroken	unbroken (confining)	broken — by reading (Wilson-line vev)

26.2 Electromagnetism: the circle’s open phase

The photon is the connection of the abelian phase itself — not a section of an associated bundle but the transporter, which is why it carries no charge of its own (Arisaka, 2026, P4-Real). Its symmetry is the one gauge factor the descent never breaks, because breaking it would require the circle’s basic winding to fail as a ledger — and holonomy classes do not fail. Hence the three textbook miracles of electromagnetism, one clause each: *massless photon* (an unbroken phase has no scale to wear); *infinite range* (a massless transporter reaches); *exact charge quantization* (charge is a winding number, and the fine-structure constant’s closed form $\alpha^{-1}(0) = 2^J + N^2 = 137$ at leading order is the ledger speaking through the phase (Arisaka, 2026, A9-SM)). Electromagnetism is what the fiber that remembers looks like when it simply *holds*: the conservative force par excellence, the keeper of the books, chiral-blind because a memory has no direction of reading.

26.3 The strong force: the closing figure

Problem 12 develops the full story: the color sector is the circle’s triangle, and its confining character is the registration rule — only trivial circuits leave the fiber. What the standard presentation calls the strong force’s strangeness — absolute confinement, no long-range field, the spectrum made only of singlets — is the visible half of a bookkeeping statement. Its conserved quantities are closures (triality inside singlets; baryon number through the $U(1)_B$ ledger); its effective range is the size of the closure, not of a Yukawa tail; and it, too, is chiral-blind — a closure does not care in which sense it was drawn. Between them, the electromagnetic and strong sectors exhaust what the circle

does with content: *hold it open* (the phase, reaching) or *close it* (the triangle, confining). Neither can change what a thing is; keepers never do.

The strong coupling’s address-dependence is worth one explicit equation. At one loop,

$$\alpha_s(\mu) = \frac{\alpha_s(\mu_0)}{1 + \frac{b_0}{2\pi} \alpha_s(\mu_0) \ln(\mu/\mu_0)}, \quad b_0 = 11 - \frac{2}{3}n_f, \quad (20)$$

where μ is the probe energy (the address), $\alpha_s(\mu_0)$ the reading at a reference address μ_0 , n_f the number of quark flavors light enough to run in loops, and b_0 the one-loop coefficient — positive for QCD ($n_f \leq 16$), which is the entire drama: as μ falls (deeper down the interval), the denominator shrinks and α_s grows, until the perturbative reading fails and the closure rule of Problem 12 takes over. The intuition, stripped of metaphor: a coupling is not a constant of nature but a boundary reading indexed by scale; Eq. (20) is the reading’s dependence on the address, its one-way $\ln \mu$ the interval’s coordinate $r = \ln(E_{\text{GUT}}/\mu)$ in laboratory units.

26.4 The weak force: the interval’s agent

The weak interaction is different in kind, and every one of its peculiarities — the full list that puzzles the student — is the signature of one fact: *it is the interaction by which the runtime acts*. The GRIP cascade’s realization in nature is the weak sector (Arisaka, 2026, A6-GRIP); the descent’s transitions — every change of stratum, every decay toward a deeper basin — are executed by it. Read the peculiarities off that identity:

- *It is the only force that changes identity* — flavor transitions, the muon’s descent to the electron, the neutron’s to the proton — because it is the mover along the ledger: the agent of GRIP-In relaxation (Arisaka, 2026, P3-Electron). The keepers conserve; the agent delivers.
- *It is chiral* — the one force that tells left from right — because it is the one force aligned with a fiber that has a direction. A keeper on the circle has no sense of reading; the agent of a one-way descent does. Parity violation, on the anatomy, is not a scandal but a signature: *the hand of the read head*.
- *It is short-range and its symmetry is broken* because the agent’s gauge sector takes its scale from the reading itself: the Wilson-line vacuum (Hosotani, 1983) — a circle-side label — sets the electroweak vev at an interval-fed address, $v = M_{\text{lock}}(2/L)^N = 246 \text{ GeV}$ (Arisaka, 2026, A9-SM): the gearbox grammar of Part II, once more.
- *Its violations cluster* — P , C , CP , flavor — because violation is the agent’s job description: the sector through which the interval acts is exactly where the interval’s one-wayness and the tape’s chirality become visible in scattering amplitudes. Problem 11’s excess was executed here; Problem 13’s descent rate (the muon lifetime as a GRIP-In observable) is timed here.

The classic question “why is the weak interaction so odd?” (Arisaka, 2026, A9-SM) thus receives a structural answer: it is not an odd member of the keepers’ family; it is not a keeper at all. *Two*

forces are the circle's, and keep; one force is the interval's, and changes. The deep two-fold division of physics — conservation and transition, being and becoming — runs straight through the middle of the standard model's table of forces, and the table has been telling us so all along.

Quantitatively, the agent's feebleness is an address, not a coupling. The measured strength of low-energy weak processes is Fermi's constant,

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8 M_W^2}, \quad M_W = \frac{1}{2} g v, \quad v = M_{\text{lock}} \left(\frac{2}{L} \right)^N = 246 \text{ GeV}, \quad (21)$$

where $G_F = 1.166 \times 10^{-5} \text{ GeV}^{-2}$ sets beta-decay rates, M_W is the W boson's mass, and v the electroweak vacuum value — the chain of Eq. (9). Read right to left: the gauge coupling g is unremarkable ($g \simeq 0.65$, the same order as electromagnetism's); what makes the weak force *weak* is M_W^2 in the denominator — the agent operates from a massive address, v , which the anatomy derives as an interval depth dressed by a circle fraction. The force is not feeble; it is *far*: suppressed by the square of the distance down the descent at which its gauge sector froze.

26.5 The two abelian companions: $U(1)_B$ and $U(1)_{Qi}$

The gauge group of Step A, Eq. (2), carries alongside the unified $SU(5)$ two abelian factors that this Part's three-force story has used without introducing, and the anatomy assigns each its character. $U(1)_B$ — the baryonic circle — is the *ledger* factor: it gauges the bookkeeping of Problem 12, counting one unit per revolution, and its boundary residue is not a new long-range force but the integrality of the guards ($Q + B \in \mathbb{Z}$); its heavy vector is a collider target of the lock cluster, not a fifth force. $U(1)_{Qi}$ — the informational circle — is the *registration* factor: the unit in which the boundary's records are billed, one unit per registered rearrangement, with the Arisaka constant Q_B the exchange rate between the circle's two currencies — energy per winding and energy per qubit — fixed by ledger integers rather than by any bath temperature (Arisaka, 2026, A7-Qi4). Their joint lesson completes the census of Problem 2: of the four circle factors the bulk carries, one reaches (the electromagnetic phase), one closes (color), one counts (baryon), and one bills (information) — four jobs, four factors, no vacancy and no spare. The anatomy has no room for a fifth force, and says so falsifiably: any confirmed long-range force beyond gravity and electromagnetism would require a circle factor the census does not contain.

26.6 Gravity, the fourth

The three gauge interactions do not exhaust the forces, and the anatomy owes the fourth a paragraph — especially since Step A of the program (§12.1) unifies gravity *with* the gauge sector as one composite connection. On the anatomy, gravity is the interaction of the *base and the interval*: its boundary strength is not a winding but an integral, $G_N^{-1} \propto \pi (1 - e^{-2K}) M_6^2$ — the warp volume of the descent (Arisaka, 2026, A4-Euclid) — which is the structural reason for its two ancient peculiarities. *Gravity is weak* because the interval integrates: the coupling is diluted by the whole depth of the throat, e^{-2K} -suppressed contributions and all, rather than being pinned by a quantized winding — and the interval integrates because it cannot hold. And *gravity alone is inseparable from irreversibility* —

horizons, entropy bounds, the thermodynamics that no other force exhibits — because it alone is bookkept on the fiber that forgets: black-hole thermodynamics (the anatomy’s most violent seam, Arisaka, 2026, C3-BH) is what the interval’s ledger looks like when curvature concentrates it. The four forces thus complete the sorting of Problem 2 with a 2+1+1 anatomy: two keepers on the circle, one agent on the interval — and one integrator, gravity, which is not a player on the tape at all but the pricing of the playback itself.

The sorting is compact enough to draw. Figure 10 places the four interactions on the anatomy: two that live by the circle, one that acts for the interval, and one that *is* the interval’s geometry.

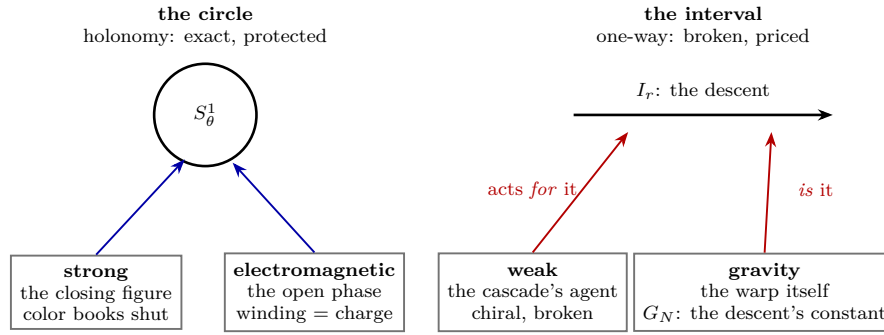


Figure 10: Four interactions, two fibers. Strong and electromagnetic: circle-side — their charges are holonomy classes, which is why they are exact and unbroken. The weak force: the interval’s agent — the GRIP cascade realized, which is why it alone is chiral, broken, and mass-giving. Gravity: not a force on the stage but the stage’s warp along the descent — why its constant alone is tied to irreversibility, and why it will not quantize like the other three. The century-old puzzle of the four interactions’ unlike characters is this sorting, unread.

One number states gravity’s foreignness. The three gauge couplings g_s, g, g' of Eq. (19) are pure numbers; gravity’s coupling is not:

$$M_{\text{Pl,red}} = (8\pi G_N)^{-1/2} = 2.435 \times 10^{18} \text{ GeV}, \quad (22)$$

the reduced Planck mass, where G_N is Newton’s constant. A dimensionful coupling means the interaction’s strength is not a reading at an address but a *conversion rate between addresses* — and that is exactly the anatomy’s assignment: G_N is the interval’s own constant (Step A of Part II), the residue of the integrated descent, which is why gravity couples to everything on the stage, cannot be screened, and does not renormalize like the other three. The failure of fifty years of graviton-by-graviton quantization is, on this reading, a category diagnosis: the other three forces are circle-side gearings and quantize as phases do; gravity is the interval’s bookkeeping, and its quantum is priced in writes, not windings.

26.7 The lock, the hierarchy, and the one unification

Problem 2’s three-way division leaves a question the standard model cannot even pose cleanly: why do the three interactions meet — why is there one gauge structure at the top at all, and why is the

weak scale where it is? The anatomy’s answers close the Part.

One structure at the top. The bulk’s gauge content is not assembled from three factors; it is one composite connection — $\text{Spin}(1, 5) \times \text{SU}(5) \times \text{U}(1)_B \times \text{U}(1)_{Q_i}$ — forced by the constitutional lemmas (Arisaka, 2026, A2-GG6; Arisaka, 2026, A9-SM), and the three boundary interactions of this Part are its three registration modes: the phase held open, the triangle closed, the agent engaged. The 5:2 trace-ratio lock and the anomaly books of BI-6 are the arithmetic face of that unity: the same ledger that balances the circle’s accounts fixes the relative normalizations the boundary measures as $\sin^2 \theta_W = L^2/(4N^3) = 25/108 = 0.2315$ and $\alpha^{-1}(0) = 2^J + N^2 = 137$ (Arisaka, 2026, A9-SM).

The hierarchy is a depth, not a fine-tuning. The weak scale sits seventeen orders below Planck because the agent’s address is at the bottom of the throat: $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} = 3.849 \text{ TeV}$ — thirty-five e-folds of descent, the exponent a ledger integer — and the electroweak vev is the gearbox form once more, $v = M_{\text{lock}}(2/L)^N = 246 \text{ GeV}$: a circle label dressing an interval depth. The hierarchy problem — *why is gravity so weak? why is the weak scale so low?* — is not solved by a symmetry protecting a small number; it is dissolved by an address: nothing is small, something is *deep*, and the depth is counted, not tuned.

The falsifiable face. The lock is not bookkeeping: the first Kaluza–Klein cluster sits at the address, 3.849 TeV, with a predicted fingerprint — spacing, spin content, branching pattern locked by the same integers — and the collider companion stakes the discovery calendar on it (Arisaka, 2026, P1-KK). A detection would read both fibers in one resonance: identity from the circle, address from the interval. Its absence, at the staked sensitivity, kills the address — and with it this section. The unity claimed in the first paragraph has a picture, and it is the most directly falsifiable one in this Part. Figure 11 runs the three inverse couplings up the radial coordinate: they meet, at one point, with boundary values that were not fitted (Arisaka, 2026, A9-SM). On the anatomy the picture reads in two registers at once. The three *starting* values at M_Z are circle-side — rational partitions of one trace, $\sin^2 \theta_W = 25/108$ and $\alpha_3^{-1} = \pi e$, quantities with nowhere to move. The three *lines* are interval-side — running is motion along I_r , which is why they have slopes at all (Problem 3). That the lines converge is the two fibers agreeing: the circle fixes where the lines start, the interval carries them, and the meeting point is not a third input.

Figure 12 shows the derivation chain that stands behind every such number.

26.8 The running and the fixed

A last sorting completes the three-force picture: among the numbers this Part has quoted, some run and some are frozen, and the anatomy says which and why. Couplings *run* — α_s falls, α creeps — because running is the interval’s business: a coupling is a reading at an address, and the flow between addresses is the semigroup itself. But the *closed forms* of Problem 2 are not couplings; they are values pinned at named addresses by circle arithmetic: $\hat{\alpha}^{-1}(M_Z) = 2^J = 128$ at the Z pole, $\alpha^{-1}(0) = 2^J + N^2 = 137$ at the infrared end, $\sin^2 \theta_W = L^2/(4N^3)$ at its matching point, the vev at its Hosotani floor. The pattern is the gearbox grammar of Part II once more, now as a rule for

GG-Theory Gauge Coupling Unification

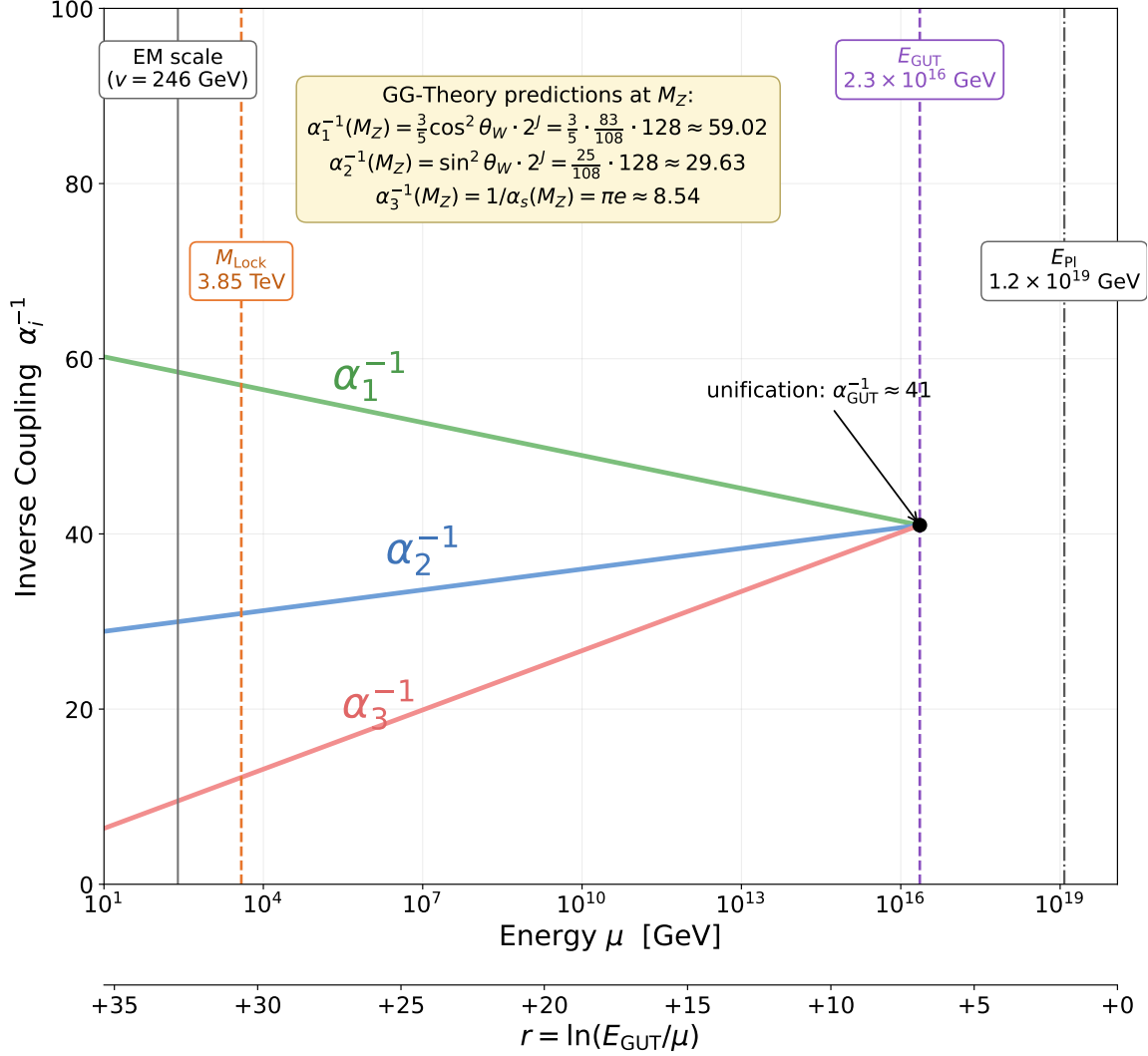


Figure 11: GG-Theory gauge-coupling unification across the 6D bulk (reproduced from [Arisaka, 2026, A9-SM](#)). Inverse couplings α_1^{-1} (green, hypercharge in $SU(5)$ normalization), α_2^{-1} (blue, $SU(2)_L$) and α_3^{-1} (coral, $SU(3)_C$) against the renormalization scale μ and the radial coordinate $r = \ln(E_{\text{GUT}}/\mu)$ — the interval's own coordinate. The boundary values at M_Z are the circle-side closed forms displayed in the panel; no continuous fitted parameter intervenes anywhere between M_Z and E_{GUT} . Four constitutional scales are marked: the electroweak scale $v = 246$ GeV, the Kaluza–Klein lock cluster $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} \approx 3.85$ TeV, the unification scale $E_{\text{GUT}} = M_{\text{Pl}} e^{-2\pi} \approx 2.3 \times 10^{16}$ GeV, and the Planck scale. Below M_{lock} the running is the standard one-loop Standard-Model flow; above it the lock cluster opens and the three couplings converge to $\alpha_{\text{GUT}}^{-1} \approx 41$ at exactly E_{GUT} . The convergence is the empirical face of the single composite connection: three registration modes of one bulk object, not three theories that happen to meet.

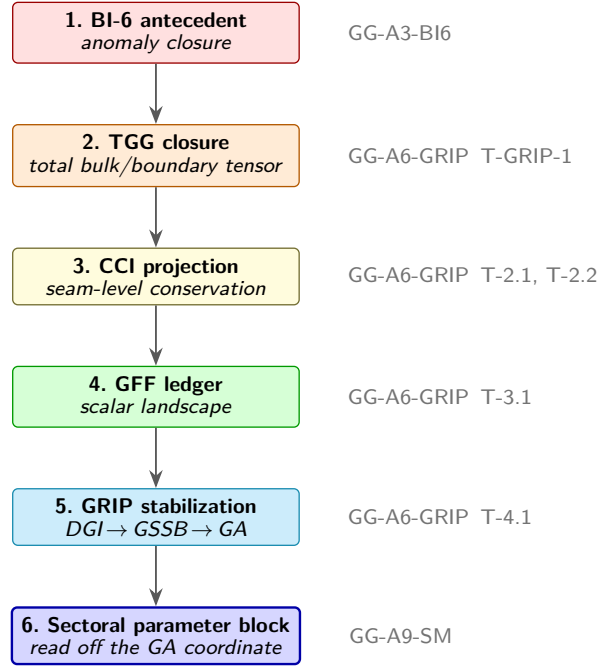


Figure 12: The universal sectoral descent ladder (reproduced from [Arisaka, 2026, A9-SM](#)). Every parameter block of the codebook obeys the same six-step descent: anomaly closure (BI-6, [Arisaka, 2026, A3-BI6](#)) → total closure of the geometry–gauge tensor → projection to the boundary seam → the GFF scalar landscape → the GRIP cascade to the selected branch → readout of the parameter values from the attractor coordinates. Each step is owned by an upstream theorem (right column); the codebook consumes the chain rather than re-proving it. This is the assembly line on which Eqs. (21) and (4) are manufactured — the reason “derived” in this paper always means derived *from something audited*, never fitted.

reading the codebook: the *trajectory* is the interval’s (continuous, one-way, scheme-dressed); the *anchor points* are the circle’s (integer arithmetic, exact). Confusions in both directions are common and both are category errors: to ask why 137 “runs away” at high energy is to mistake an anchor for a trajectory; to hope a running calculation will one day *derive* 137 is to mistake a trajectory for an anchor. The codebook’s precision program (Arisaka, 2026, A9-SM) lives entirely in keeping the two straight — and its twenty-eight-parameter audit is the demonstration that, kept straight, the anchors suffice.

26.9 Seminar questions

Why does electromagnetism not confine? Because its circle factor is abelian and *held open*: a single winding is a complete, registerable book (any integer charge is a lawful boundary state), so nothing forces closure into neutral composites. Color’s registration rule bites because its triangle books balance only in triples — the difference is not in the strength of a force but in the arithmetic of the ledger.

Why is the weak force short-range but not confining? The two properties come from different columns. Range is an address property: the agent’s bosons are massive (the Wilson-line vev sets their scale), so its reach is Yukawa-cut. Confinement is a ledger property: the weak sector’s books close on singles, so nothing is imprisoned. A force can be short-range and free (weak), long-range and free (EM), or effectively zero-range and confining (strong) — the four-force table’s rows are independent because the anatomy’s columns are.

Where is the graviton in this picture? Gravity is the integrator, and its quantum is the boundary’s reading of bulk metric transport — I treat the graviton question at the register of the black-hole and cosmology companions rather than as a fifth entry in the force table, precisely because pricing is not keeping or changing: the deep statement is not “gravity is another gauge force” but “gravity is the bookkeeping of the descent itself,” which is why it couples to everything, screens nothing, and alone carries horizons.

Why do the couplings meet near the top? Because they were never three: the bulk carries one composite connection, and the three boundary couplings are its three registered residues, read at addresses. Their near-meeting toward the ultraviolet is the census seen in reverse — three shadows converging toward the one object that casts them — and the ledger’s arithmetic (2^J , $L^2/4N^3$) is what the meeting-point bookkeeping looks like when the integers are made explicit.

26.10 The scorecard of the sorting

The Problem’s claim is structural, so its scorecard should be structural too. Count what the two-keepers-one-agent-one- integrator sorting explains with no further input: why exactly one force is long-range and gentle (one factor held open); why exactly one confines (one closing figure); why exactly one is chiral and identity-changing (one fiber with a direction); why exactly one prices horizons (one integrator); why charge is quantized (windings); why the photon is massless and

neutral (the gearing carries no dial); why anomaly coefficients cannot run (circle bookkeeping); why the vev sits where it does (the gearbox); and why no fifth force appears (the census is full: four circle factors, four jobs, no vacancy). Nine structural facts, most of them memorized by every student as separate brute features of the standard model, all of them rows of one table — and the table’s exposure is a single address: 3.849 TeV, where the composite’s first rung either appears with its fingerprint or does not.

27 Problem 3. The Origin of Local Gauge Invariance and Renormalization

27.1 Two principles that explain everything and themselves poorly

Ask a field theorist what dictates the form of the fundamental interactions and the answer is one phrase: local gauge invariance. Demand that the phase of a matter field be adjustable independently at every point of spacetime, and the gauge fields — the photon, the gluons, the weak bosons — appear as the price of the demand, with their couplings and self-interactions fixed. It is the most successful principle in physics. It is also, examined closely, the strangest: Noether proved in 1918 (Noether, 1918) — in the same paper as her famous theorem — that a symmetry of this local kind delivers *no* conserved quantity, only an identity among the equations of motion, true whether or not anything obeys them. A local gauge transformation changes nothing physical; it is, in the standard phrase, a redundancy of description. Physics’ master principle is a demand about bookkeeping. Why should nature care?

The second principle is renormalization. Quantum field theory’s raw predictions diverge; the cure absorbs the divergences into a finite set of couplings that “run” with the energy scale; the result agrees with experiment to eleven decimal places. Yet its founders were openly uneasy — Dirac called it sweeping infinities under the rug — and the modern Wilsonian understanding, while far more satisfying, still leaves a question standing: the renormalization group’s flow is famously *irreversible* (coarse-graining loses information; c-theorems and their kin make the one-wayness precise), and nothing in the underlying reversible dynamics explains where that arrow comes from, or why the scale parameter behaves so much like a dimension that field theorists routinely draw it as one.

The anatomy’s claim: both principles are the two fibers, made law — gauge invariance is what the circle looks like from the boundary, and renormalization is what the interval does. Neither is a trick of description; both are geometry.

27.2 Noether’s second theorem, in plain English

The distinction that carries this Problem was drawn at the very beginning, and is worth one paragraph of care (Arisaka, 2026, W1-Symmetry). A *global* symmetry — rotate every phase everywhere by the same amount — constrains motion: Noether’s first theorem turns it into a conserved current, a physical statement. A *local* symmetry — rotate each phase independently, point by point — cannot constrain motion, because it can undo any motion: her second theorem shows it yields identities, not charges, and Elitzur later proved the consequence (Elitzur, 1975) in

full rigor — a local symmetry cannot even break, because there is nothing physical there to break. So the standard model is built on a principle which, by the sharpest theorems available, has no physical content. The resolution cannot be to deny the theorems. It must be to find the physical thing that *hides behind* the redundancy.

27.3 What gauge symmetry is: the unreadable circle

The anatomy supplies the hidden thing. The gauge phase is not an abstract label; it is a coordinate — position around the compact fiber S^1_θ — and OGGEF states its fate: no boundary protocol can register a fiber coordinate. The phase at a point is unreadable *as a matter of law*, not of technology; only differences of phase around closed circuits — holonomies — survive projection to the boundary. Now run the logic forward and the two mysteries of gauge theory resolve into one statement each:

- *Why is the local phase a redundancy?* Because it is the coordinate of an unreadable fiber. Noether II and Elitzur were exactly right: the pointwise phase has no physical content — it is the part of the geometry the boundary cannot hold. The “redundancy” is not a defect of our description; it is the *shadow of a real circle* that observation cannot enter.
- *Why does a redundancy dictate the interactions?* Because what remains after the unreadable part is removed — the holonomies — is not nothing: it is everything. By the Wilson-loop reconstruction, a gauge field *is* its holonomies; the interactions are the transport of the fiber nothing can read; and demanding local gauge invariance is simply demanding that a theory speak only of the readable — which forces it to speak of transport, and transport is force. The Aharonov–Bohm effect is this Problem’s tabletop witness (§13): a phase invisible along every open path, physical around the closed one.

One more classic puzzle collapses with the same move: charge quantization. If the gauge group were an abstract $U(1)$, charge could take any real value; measured charges come in exact integer ratios to one part in 10^{21} . On the anatomy the phase is a *compact geometric circle*, so its conjugate charge is a winding number — an integer because the fiber closes. The oldest precision fact in electromagnetism is a topology statement about the sixth dimension.

The reading extends upward. Local gauge invariance is the circle’s unreadability stated in a *closed* theory — the static form of the law. In the cohort’s constitutional ladder (POS-1: LGI/DGI/GGI) the same invariance has a dynamical form: *Dynamical Gauge Invariance*, the opening stage of the GRIP engine (§16), in which the gauge directions themselves become dynamical because an open system’s environment keeps shifting the phase conventions (Arisaka, 2026, A7-Qi4) — the invariance is then held by an equivalence class of boundary generators, not of field configurations. DGI is LGI carried through the open dynamics: the circle’s invariance transported by the interval’s semigroup. What Problem 1 does for the state (unitary on the circle, write on the interval), the ladder does for the symmetry itself.

The principle in symbols, so the plain-English reading has something exact to hold. A local gauge transformation is the simultaneous rewriting

$$\psi(x) \longrightarrow e^{iq\chi(x)}\psi(x), \quad A_\mu(x) \longrightarrow A_\mu(x) + \partial_\mu\chi(x), \quad (23)$$

where ψ is a charged matter field, q its charge, A_μ the gauge potential, and $\chi(x)$ an *arbitrary function of position* — a different phase convention at every point. “Gauge invariance” is the statement that physics is unchanged under Eq. (23) for every χ ; and since χ is arbitrary, anything that changes under it — the local value of the phase, the potential itself — is convention, not physics. What survives every χ is exactly what Eq. (12) collects: the loop integrals, on which $\partial_\mu \chi$ integrates to zero around any closed circuit. That is the unreadable-pointer statement made exact: the circle’s absolute angle is χ -shiftable, its closed-loop content is not.

27.4 What renormalization is: motion along the interval

Now the second principle. In the Wilsonian picture one integrates out physics scale by scale and watches the couplings drift; the scale parameter μ is a bookkeeping device, and the flow’s irreversibility a property of information loss. The anatomy promotes the picture to geometry: the scale is the fifth coordinate, $r = \ln(E_{\text{GUT}}/\mu)$ — a direction of the bulk, as real as the circle — and the renormalization flow is *transport along the interval*. Each ingredient of the textbook toolkit acquires an address-book meaning:

- A *running coupling* is a reading at an address: $\alpha_s(2 \text{ GeV})$ and $\alpha_s(M_Z)$ are the same circle-anchored quantity inspected at two stations of the descent.
- A *scheme choice* is address bookkeeping — a convention for labeling stations, physical in none of its arbitrariness, exactly as the textbooks insist.
- The flow’s *irreversibility* is the interval’s semigroup: coarse-graining has no inverse because the fiber has none. The c-theorems are the laboratory-scale face of the same one-wayness that runs cosmic history (Problem 13) — one arrow, met twice.
- *Renormalizability* itself becomes a census criterion: the interactions that survive the flow — the relevant and marginal ones — are the content the interval can carry to the infrared; the rest is left behind at high addresses. That the standard model is renormalizable is, on this reading, the statement that its content is exactly what a descent can deliver.

Why does the “sweeping of infinities” work? Because there were never infinities in the geometry — only the pretense that the interval was infinitely long in both directions. The bulk’s interval runs from the GUT edge to the infrared: a finite descent, $K = 35$ e-folds to the lock, with the ultraviolet end a real edge rather than a limit. Effective field theory’s great lesson — every theory has a cutoff and a domain — is the interval’s finiteness, learned from inside.

Figure 13 draws the two principles side by side: the sealed dial whose absolute pointer no experiment reads, and the descent along which every coupling is a reading at an address.

Here too one equation carries the concept. A coupling g measured at resolution scale μ obeys the renormalization-group equation

$$\mu \frac{dg}{d\mu} = \beta(g), \quad (24)$$

where β — computable within the theory — gives the rate at which the reading changes per e-fold of scale. The equation’s form is the lesson: the derivative is with respect to $\ln \mu$, so the natural

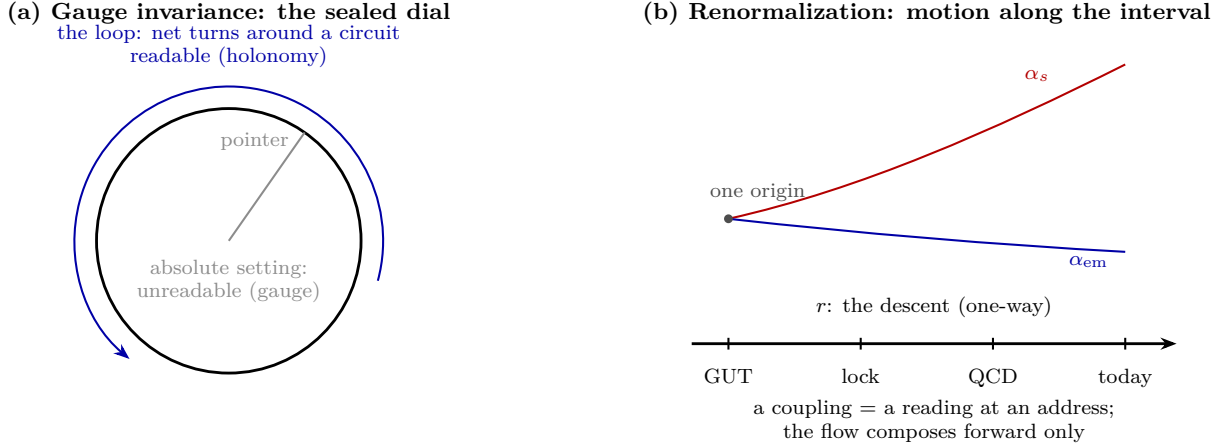


Figure 13: The two principles, drawn. (a) Gauge symmetry: the compact fiber’s absolute pointer is unreadable, and “gauge invariance” is the law that physics speak only of the readable — the net turns around closed circuits. (b) Renormalization: couplings are not constants but readings at addresses on the fifth dimension, and the flow’s famous irreversibility is the interval’s semigroup. One geometry, both principles — neither imposed, both read.

coordinate of the flow is logarithmic in energy — precisely the interval’s coordinate $r = \ln(E_{\text{GUT}}/\mu)$ — and the flow is first-order: the reading at one address determines the reading at the next, with no memory and no way back (Eq. (14)). The sign of β sorts the forces: $\beta > 0$ for electromagnetism (the reading grows toward the ultraviolet), $\beta < 0$ for the strong force (Eq. (20)’s $b_0 > 0$: the reading grows toward the infrared, the seed of confinement).

27.5 A short history of the gauge idea, reread

The gauge principle’s own history, reread on the anatomy, is a century of converging on the circle without naming it. Weyl’s 1918 original proposed local *scale* invariance — an interval idea — and failed physically (atoms would remember their histories); his 1929 repair replaced scale by *phase*, and worked. On the anatomy the repair is a fiber swap: local readjustability belongs to the compact fiber, whose pointwise value is lawfully unreadable, not to the open one, whose coordinate is physical (it is the RG scale — Problem 13’s chronology rides on it). Yang and Mills generalized the phase to internal circles (Yang and Mills, 1954) and spheres; Aharonov and Bohm showed the phase’s loop content is physical; Wilson made loops the theory’s variables; Hosotani showed loop values can choose vacua. Each step moved the weight from the connection (unreadable) to the holonomy (the content). The anatomy is the terminus of that motion: it takes the last step of saying the circle is a *place* — the sixth dimension — so that the gauge principle stops being a principle about our descriptions and becomes a fact about the bulk: *physics is the transport of an unreadable fiber*. At the terminus the old philosophical scandal (why should nature obey a bookkeeping rule?) inverts: nature does not obey it — nature *is* it, and we obey it when we describe her lawfully.

Figure 14 compresses that century into one diagram — the first white paper’s ladder, reproduced here because this Problem is its structural reading.



Figure 14: The century’s ladder: seven steps from Noether to Hopkins–Singer (reproduced from Arisaka, 2026, W1-Symmetry). Reading upward, each step in the history of gauge theory says less about how things move and carries more of its content in an integer; the lower rungs are algebra and convention and cannot fail, while from the fifth rung up something can fail — by a whole number. The gauge idea’s century, compressed: a walk from dynamics toward topology, arriving at the circle’s protected integers — the destination this Problem reads as where the principles came from all along.

27.6 Worked intuition: the sealed dial

Carry one image. Every point of space wears a sealed dial: a pointer that no instrument can photograph, by law. What can be measured is only this: carry a test charge around a closed path and count how far the pointer has net-rotated when you return — the holonomy. Now every strange clause of gauge theory becomes a sentence about the seal. *Gauge transformations* re-zero the unreadable pointers; nothing measurable can care, which is invariance. *The vector potential* is the pointer-to-pointer gearing — unphysical pointwise, physical in its loop totals, which is Aharonov–Bohm. *Charge quantization*: the dial is a closed circle, so loop totals come in whole turns — the argument whose first instance is Dirac’s monopole quantization (Dirac, 1931). *The photon* is the gearing itself, which is why it is massless and chargeless: gearing carries no dial of its own. And *anomaly exactness* (next section) is the statement that the number of teeth on the gears is a manufacturing constant of the geometry — an integer the flow downstream can never wear away.

27.7 Asymptotic freedom and the far end of the interval

The interval reading earns a bonus that deserves its own page: the qualitative shape of the strong coupling’s run. Asymptotic freedom — the strong force weakening at short distances, Nobel-crowned and experimentally exquisite — is, in address language, the statement that the color reading falls toward the ultraviolet end of the interval and grows toward the infrared, until at the confinement scale the perturbative reading fails and the circle’s closure rule (Problem 12) takes over the description. The anatomy adds no new computation to the beta function — the running is standard physics, inherited whole — but it adds the census remark that dissolves a familiar puzzlement: students

ask *where* the coupling “really” has its value, as if one address were true and the others apparent. No address is privileged; the couplings are readings along a real direction, the way temperature has a value at every altitude of an atmosphere; and the closed forms of the codebook (Problem 4) are anchored at *named* addresses — α^{-1} at the infrared end, 2^J at the Z pole — precisely because only named addresses are answers. The interval, once seen, also explains why the three gauge couplings converge toward the ultraviolet at all: they are three readings of one composite connection (Problem 2’s unification), taken closer and closer to the edge where the composite was never split.

27.8 Three tiers of protection, and the Higgs

The two principles now have their fibers. Before the dictionary collects the translations, one distinction has to be drawn that the Part has so far let pass, because without it the anatomy appears to contradict itself — and because with it the anatomy pays its largest single debt.

The apparent contradiction is this. §66.2 proves that circle-side quantities cannot run: they are homotopy data, the flow is continuous, and nothing continuous acts on an integer. Yet the electroweak vacuum value v is set by a circle-side modulus, and v runs. So does the Higgs mass. Either the theorem is wrong or the sorting is.

Neither. *Circle-side quantities are not all protected the same way*, and the ones that differ are exactly the interesting ones (Table 7).

Table 7: Why some circle-side quantities run and others cannot. Tier 1 is winding data — charge, anomaly coefficients, the family count, the parities — and it cannot move, because an integer has nowhere to move. Tier 2 is a continuous modulus of the circle — the Wilson-line phase that *selects* the electroweak vacuum (Problem 2), and the Kaxion’s angle (Problem 7); it moves, and what protects it is non-locality, since a Wilson line is not the value of any local operator and no local counterterm can generate a potential for it. The electroweak doublet itself is not a tier-2 object, and the table does not put it there: where it sits, and what that costs, is the text below. Tier 3 is the interval’s addresses — masses, scales, rates, epochs — which run, and must, because running is what an address does.

Tier	What it is	Can it move?	What protects it
1	winding data: charge, anomaly coefficients, the family count, parities	No	integrality. An integer has nowhere to move. This is the no-running theorem of §66.2 and the seventh rung of Arisaka (2026, W1-Symmetry)
2	a continuous modulus of the circle: the Wilson-line phase — the electroweak selector (Problem 2), the Kaxion (Problem 7)	Yes	non-locality. A Wilson line is not the value of any local operator, so no local counterterm can generate a potential for it; whatever potential it acquires is nonlocal, finite, and calculable
3	interval-side addresses: masses, scales, rates, epochs	Yes, and must	nothing. Running is what an address does

Tier 1 is the circle at its most familiar — the fiber that remembers, remembering exactly. Tier 3 is the interval doing its work. Tier 2 is the interesting case, and this paper has one important instance of it.

Why the Higgs is the Standard Model’s problem child. A scalar’s mass is the coefficient of a local operator of dimension two, so every loop drags a term of order $\Lambda^2/16\pi^2$ into it. With Λ anywhere near the Planck scale, the bare value and the loop corrections must agree to some thirty decimal places for the observed mass to survive — the naturalness problem, and the reason a generation of physicists expected new particles at the electroweak scale to enforce a cancellation. On the anatomy that reasoning is sound but misapplied. It has to be said carefully, though, because the tempting version of the correction claims more than the cohort holds, and the two halves of the honest version pull in different directions.

What is tier 2 is the selector, not the doublet. The holonomy W_θ of Eq. (64) is a periodic angle, and a local counterterm quadratic in that angle does not exist, because the angle is not gauge-invariant on its own — only closed-loop functions of it are. One cannot quadratically renormalize a holonomy. The potential the angle does acquire comes from fields *winding* the circle, which is a nonlocal effect, exponentially convergent in the winding number, and finite (Hatanaka, Inami & Lim, 1998). That is a theorem about the angle, and the angle is the electroweak sector’s *selector*: the gauge-invariant order parameter whose stationary branch $\sin \theta_H^* = (2/L)^N$ fixes where the vacuum value lands, $v = M_{\text{lock}} \sin \theta_H^* = 246$ GeV, at the conditional grade the codebook prints for that theorem (Arisaka, 2026, A9-SM).

What the four-dimensional doublet is, and what does not protect it. It is the $(\mathbf{1}, \mathbf{2})_{+1/2}$ inside a bulk $\mathbf{5}_H$ — an ordinary scalar with an ordinary vacuum value, required by the fermion mass sector and selected as the minimal representation that serves it (Arisaka, 2026, A9-SM). It is not a component of the connection. The coset directions the orbifold parity keeps in A_θ are colored, there is no color-singlet weak doublet anywhere in the adjoint of the bulk group, and a vacuum value along a coset direction would give the gluon a mass. So the nonlocality theorem does not reach the doublet, and the sentence “the Higgs mass is finite because no local counterterm exists for a Wilson-line phase” is not available here. The codebook companion says so in its own words, and this paper follows it (Arisaka, 2026, A9-SM).

What survives is smaller, and it is the whole of what §30 spends. The large hierarchy is geometric: the electroweak scale is separated from the Planck scale by the fixed transport $e^{-K}(2/L)^N$ — an address, not a cancellation — and the residual protection of a doublet registered at the infrared end is the warp factor, as in any warped construction. The little hierarchy — the doublet’s own radiative stability — is not solved here, and the codebook’s open list says so. Supersymmetry answers naturalness with a symmetry, and a symmetry can break; its preferred region is now excluded (Problem 4). Topology and locality have nothing to break. *Protection without symmetry*, the destination of the ladder in the companion review, is not an abstraction about differential cohomology: it is why the electroweak scale has an address rather than a coincidence. It is not, on the cohort’s own group theory, a protection theorem for the scalar that sits at that address.

The honest limit of the claim. Tier 2 is weaker than tier 1, and blurring them would be the easiest overclaim in this Part. A tier-1 quantity cannot move at all: an anomaly coefficient that ran would falsify the framework (§48). A tier-2 modulus is an angle — it moves, and v and m_H run like the addresses they are. What tier 2 buys is not fixity but *finiteness*, and it buys it for

the selector: a quantity the theory owes a calculation for, rather than a quantity that absorbs a divergence. The owing is recorded honestly in the codebook companion, where the electroweak vev lands at +0.045% and the Higgs mass, which requires the potential’s curvature rather than merely its minimum, is a percent-and-a-half low with the normalizing step not yet computed (Arisaka, 2026, A9-SM). Two further items are owed there, and are printed here rather than left for a reader who checks. The vacuum-value theorem is a *boundary readout*: the Wilson line’s own flat mode on the interval is weighted at the ultraviolet end and registers $m_W \approx 2 \times 10^{15}$ GeV, thirteen orders above the measured value, so that mode cannot be the 246 GeV field — and which infrared mode is has not been settled. And on every placement of the electroweak Kaluza–Klein tower computed so far, a tower at the lock returns an oblique $T = 1.7$ against a global fit of 0.00 ± 0.06 , which is twenty-eight standard deviations and is not closed by any reasonable revision of the inputs. Both stand on the codebook’s open list as one problem, and this paper does not write around it. The framework has converted an unnatural input into an owed calculation and has not finished paying. That is a better place to stand than thirty decimal places of cancellation, and it is not the same thing as a solved problem.

27.9 The dictionary, in one table

For reference, the Problem’s translations collected — each row a standard concept on the left, its anatomy reading on the right:

Table 8: The field-theory dictionary, one line to a concept: a standard term of gauge theory on the left, its reading in the two-fiber anatomy on the right. A local gauge transformation is a re-zeroing of unreadable pointers, the potential A_μ is the pointer-to-pointer gearing, gauge invariance is the law that one speak only of the readable, the Wilson loop is what is readable — net turns around a circuit — electric charge is a winding number of the compact fiber, and the photon is the gearing itself, with no dial of its own. The lower half does the same for the interval: the RG scale μ is an address on the fifth dimension, a running coupling is a reading at an address, scheme dependence is address bookkeeping, and the irreversibility of the flow is the interval’s semigroup. Nothing in the right column is new physics; the table is the translation the rest of the Part uses.

Field-theory concept	Anatomy reading
local gauge transformation	re-zeroing of unreadable pointers
gauge potential A_μ	pointer-to-pointer gearing
gauge invariance	the law: speak only of the readable
Wilson loop / holonomy	the readable: net turns around a circuit
electric charge	winding number of the compact fiber
the photon	the gearing itself (no dial of its own)
RG scale μ	address on the fifth dimension
running coupling	a reading at an address
scheme dependence	address bookkeeping (unphysical, as taught)
RG irreversibility	the interval’s semigroup
renormalizable operator	content the descent can carry to the IR
anomaly coefficient	circle-side pairing integer (cannot run)
anomaly cancellation	the circle auditing the interval’s books

The table’s uniformity is the Problem’s result: thirteen standard notions, two fibers, no exceptions — quantum

field theory’s formal apparatus, reread as the operating manual of a geometry it never named.

27.10 Questions students ask

Why this gauge group and not another? The census answers in two layers. The bulk’s composite group — $\text{Spin}(1, 5) \times \text{SU}(5) \times \text{U}(1)_B \times \text{U}(1)_{Q_i}$ — is forced by the constitutional lemmas (Problem 2’s unification section); and the boundary’s familiar $\text{SU}(3) \times \text{SU}(2) \times \text{U}(1)$ is its registered residue: the part of the transport whose holonomies survive projection. The standard model’s group was never a choice from a catalog; it is the readable shadow of the one composite the geometry admits.

Why is charge conserved even through measurements? Because measurement is an interval-side write (Problem 1), and charge is circle-side data: the write registers, it cannot deform. The textbook wonder that “collapse” respects every superselection rule is, on the anatomy, no wonder at all — the event that could violate a winding lives on the wrong fiber to touch one.

Could gauge invariance be emergent? Several respected programs derive gauge structure from more primitive rules; the anatomy neither needs nor forbids such a layer, but it sharpens the requirement: any successor must reproduce a sector with exactly the circle’s profile — unreadable pointwise, loop-exact, integer-charged — and a sector with exactly the interval’s — one-way, unprotected, address-like. Emergence that delivers the pair delivers this Problem’s physics; emergence that delivers less delivers less. As with Problem 15, the anatomy functions as a constraint on all candidate deeper theories — which is the most a structural claim can honestly be.

Is renormalization still “effective”? Yes — gloriously so. Nothing in the interval reading disturbs the practical Wilsonian toolkit; it explains why the toolkit works and where its scales live. The one working habit it retires is apology: the twentieth century’s sense that renormalization was provisional, a stand-in for a finite future theory. On the anatomy the flow is not scaffolding around the theory; it is a load-bearing wall of the geometry — the fifth dimension, carrying weight.

27.11 The anomaly: the circle audits the interval

The two principles meet in exactly one place, and the meeting is the sharpest exhibit of this Problem. An anomaly is a classical symmetry that quantization cannot keep — the one lawful failure of the gauge principle — and its coefficients have a remarkable property: they are exact integers, computed at one loop and corrected at none, identical at every scale. On the anatomy this is inevitable: anomaly coefficients are circle-side bookkeeping — topological pairing data on the fiber that remembers — so they cannot run, because running is the other fiber’s business and the interval has no holonomy to renormalize (Arisaka, 2026, A3-BI6). The cancellation of anomalies is then the circle auditing the interval’s books: a consistency contract between what the descent carries and what the topology permits, enforced in integers. The cohort’s own bulk passes the audit by the six-dimensional Green–Schwarz mechanism (Green and Schwarz, 1984), and the audit’s byproduct is the integer ledger $(M, N, L; J, K)$ from which the codebook of Problem 4 is built — the deepest example in physics of a redundancy’s bookkeeping paying out measurable numbers. The seam where the two-sided audit is proved end to end is Appendix H of the family-number paper (Arisaka, 2026, P2-N3): *what the circle quantizes is what the interval delivers*.

The audit has an exact face in the Standard Model itself. For each generation, gauge consistency requires the

fermion hypercharges Y_f to satisfy, among others,

$$\sum_f Y_f = 0, \quad \sum_f Y_f^3 = 0, \quad (25)$$

the sums running over the fifteen chiral fermions of one generation with their color multiplicities. These are not approximate relations improved by higher orders; they are exact integer arithmetic — the quark and lepton hypercharges conspire to cancel — and a single fermion added or removed breaks them. The physical reading: an anomaly is a quantum failure of a classical bookkeeping, and Eq. (25) is the condition that the books close. That the observed matter content satisfies it exactly — forcing, famously, the quark charges to be thirds — is the circle auditing the boundary’s content, and the six-dimensional version of the same audit (Arisaka, 2026, A3-BI6) is what locks the cohort’s ledger.

Figure 15 draws the crossing itself.

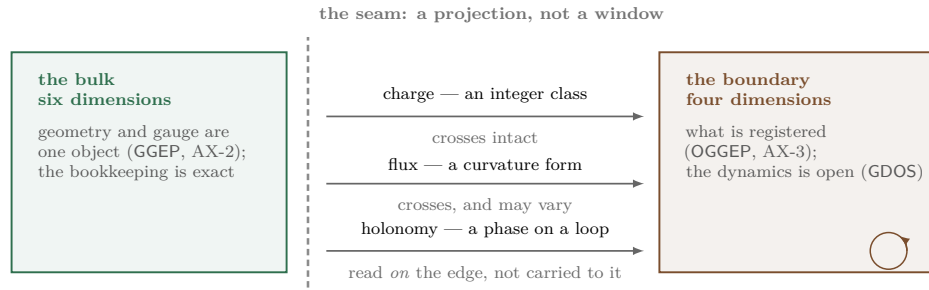


Figure 15: The seam: what crosses from bulk to boundary (reproduced from Arisaka, 2026, W1-Symmetry). Three kinds of data cross from the six-dimensional bulk to the four-dimensional stage, and they cross differently: the integer class crosses intact (nothing continuous can deform it), the curvature form crosses and may vary, and the holonomy — being a statement about a loop — is evaluated *on* the boundary rather than transported to it. The asymmetry is this Problem’s content in one picture: what arrives exact arrives from topology; what arrives adjustable arrives from geometry; and the audit of Eq. (25) polices the crossing.

27.12 Where each fiber stops: the one number the anatomy cannot reach

Every subsection of this Problem so far has been an addition. The circle gave gauge invariance and exact charge; the interval gave renormalization and its arrow; the seam between them gave the anomaly ledger. It is worth spending one subsection on subtraction, because the anatomy’s limits are where its content is easiest to check — and because the sharpest test available sits exactly here, in the most precisely measured number in physics.

Take the electron’s magnetic moment. Dirac’s equation gives $g = 2$ for free: a phase geared minimally to a field has precisely that moment, and nothing was chosen. That is the circle at work, and it is the cleanest single payment the compact fiber ever makes. But the measured value is not 2. It exceeds it by about one part in eight hundred, and the excess $a = (g - 2)/2$ is known to twelve significant figures — a number the discipline has spent seventy-five years computing, one Feynman diagram at a time.

So the question the anatomy has to face is direct. Two extra dimensions, one of which *is* the gauge phase and one of which *is* the renormalization scale: what do they say about a ?

They say nothing, and both silences have a reason.

The interval cannot reach it, because a carries no scale. This is GG-A5-GDOS’s theorem T9.9 (Arisaka, 2026, A5-GDOS), and its argument is one line: the radial coordinate is by construction conjugate to scale, so a quantity independent of scale lies in the directions orthogonal to it, and a change of variables cannot reduce the information content of something already independent of the variable being changed. For the magnetic moment the scale-independence is not an observation but a theorem: a is the coefficient of an operator of mass dimension five, a renormalizable theory carries no counterterm for such an operator, so the coefficient must come out finite — and a finite, dimensionless, on-shell number cannot depend on the sliding scale at all. The famous rule that $g - 2$ “does not run” is a statement about an operator dimension. What runs is α ; a is what you get once α has been read.

The circle cannot reach it either, because a is not an integer. This is the same argument that made the circle powerful, run backwards. Flat connections on S^1_θ are classified by $\pi_1(S^1) = \mathbb{Z}$, and the whole force of §27.8 was that nothing continuous can move between the points of a discrete set — which is why charge is quantized, why anomaly coefficients cannot run, and why class data are the same in every region of the sky. All of that is *integers*. But $a = \alpha/2\pi + \mathcal{O}(\alpha^2)$ is not an integer, not a winding number, and not a characteristic class. The fiber that protects whole numbers has no grip on a transcendental one.

So the anomalous moment falls between the two fibers: too continuous for the circle, too scale-free for the interval. On the three tiers of §27.8 it belongs to none of them — it is neither protected content nor an address, but the boundary’s own arithmetic. The twelve thousand diagrams are what that arithmetic costs, and the anatomy neither shortens the bill nor claims to.

What the anatomy does supply, which is not nothing. It supplies the number you feed in. The prediction for a is only as good as the α it is computed with, and $\alpha^{-1}(0) = 2^J + N^2 = 137$ is a ledger identity here rather than a measurement (Arisaka, 2026, A9-SM). It supplies the reason there is a lepton sector to have a moment at all. And it supplies, through GG-P3-Electron (Arisaka, 2026, P3-Electron), the statement that the electron’s own contribution to a is exactly zero at every order — all of the anomaly is the vacuum’s, none of it is structure, and that is a prediction with a kill criterion rather than a hedge.

Why the refusal is worth more than an answer would be. A framework that could produce $\alpha/2\pi$ from geometry could produce almost anything from geometry, and the reader would be right to stop believing it. The division this Problem draws is the opposite: the compact fiber says what is exactly conserved, the open fiber says at what resolution it is being read, and the arithmetic of the boundary says what follows. Confusing the three is how a structural framework turns into numerology.

There is a reward for having said this in advance, and it arrived while this cohort was being written. The framework has no spare sector with which to manufacture a contribution to the muon’s anomaly, and said so plainly — a standing exposure, since for several years the muon measurement sat some four standard deviations from the Standard-Model evaluation and a great many models were built to close that gap. The gap has since closed on its own: the hadronic term was re-evaluated on the lattice and the discrepancy fell below one standard deviation. The anomaly the anatomy could not have explained turned out not to need explaining.

Physics intuition: the sealed dial tells you *what* charge is, and gives you $g = 2$; the elevator tells you how strong that charge *looks* from the floor you are standing on; and the last twelve decimal places are the room the electron is standing in, which is never empty and has to be summed over by hand. Three different kinds of fact, and this Problem’s claim is only that the first two are geometry.

Where this Problem declines: no value of a_e or a_μ is predicted, sharpened, or bounded here or anywhere in the cohort. A future claim to have computed one from the two fibers would contradict Eq. (25)’s own logic — what arrives exact arrives from topology, and $\alpha/2\pi$ is not exact in that sense.

27.13 The principles, re-founded

Summarize the Problem as a before-and-after. *Before*: local gauge invariance is a redundancy mysteriously promoted to a master principle; renormalization is a successful procedure with an unexplained arrow; charge quantization needs monopoles or grand unification; anomaly exactness is a happy accident of one-loop topology. *After*: all four are one geometry — the phase is a real, compact, unreadable fiber (so gauge “symmetry” is the law that physics speak only of its transport, and charge is its winding); the scale is a real, open, one-way fiber (so renormalization is descent, and its arrow is the composition law of the flow along that fiber rather than a statistical accident); and the anomaly ledger is the seam where the circle’s exactness disciplines the interval’s flow. The grades are inherited: the identifications are the constitution’s (AX-2, AX-3); their quantitative payout is Problem 4’s. **Kill**: a measured violation of charge quantization; an anomaly coefficient found to run; a physical (scheme-independent) reversal of RG flow; or the failure of the ledger’s arithmetic anywhere the codebook stakes it — each would break this Problem at a named joint. None has ever been observed.

28 Problem 4. Too Many Free Parameters in the Standard Model and Λ CDM

28.1 The count, and why it hurts

The Standard Model works by taking numbers from experiment and giving back predictions of everything else. The taking is the embarrassment: some twenty-eight quantities — twelve fermion masses, the mixing angles and phases of quarks and neutrinos, three gauge couplings, the Higgs sector, the strong-CP angle — must be measured, not derived. Cosmology adds its own sheet: the density fractions, the expansion rate, the primordial tilt and amplitude. Einstein’s hope — a theory in which “there are no arbitrary constants” — has drifted so far out of reach that the modern literature largely inverted it: perhaps the constants are *environmental*, drawn from a landscape, explained (if at all) anthropically (Problem 15). The parameter count is not a cosmetic flaw; it is the discipline’s standing confession that it describes the world rather than accounts for it.

Notice what kind of solution would count. Fitting the twenty-eight with twenty-nine deeper parameters counts for nothing. Deriving a few celebrated ratios while leaving the rest free counts for little. What is wanted is a *grammar*: a reason why this list, these values, and no freedom — with the derivation exposed, entry by entry, to falsification.

28.2 The codebook claim

The cohort’s claim, developed at full length in the codebook paper (Arisaka, 2026, A9-SM) and carried here in the anatomy’s language: the parameters are not dials but *readings*, and every one obeys a single grammatical rule —

Every Standard-Model parameter is a holonomy-class label wearing a descent address: the label is the circle’s, the address is the interval’s.

The quantized content — charges, representations, mixing angles on the flavor lattice, the weak angle’s rational partition — is circle-side: arithmetic of the five ledger integers $(M, N, L; J, K) = (1, 3, 5; 7, 35)$ and of π , exact, unable to run, which is why these entries arrive as closed forms with no error bars of their own. The continuous-looking content — masses, scales, the vev — is interval-side: exponential addresses of the descent, computed from the same integers through the warp. Nothing in the sheet is a third kind of thing, and that is the falsifiable core: *no third species of primitive*.

Figure 16 draws the claim as a tree: five constants and five integers at the root, the twenty-eight parameters at the leaves, and derivation arrows — not fits — in between.

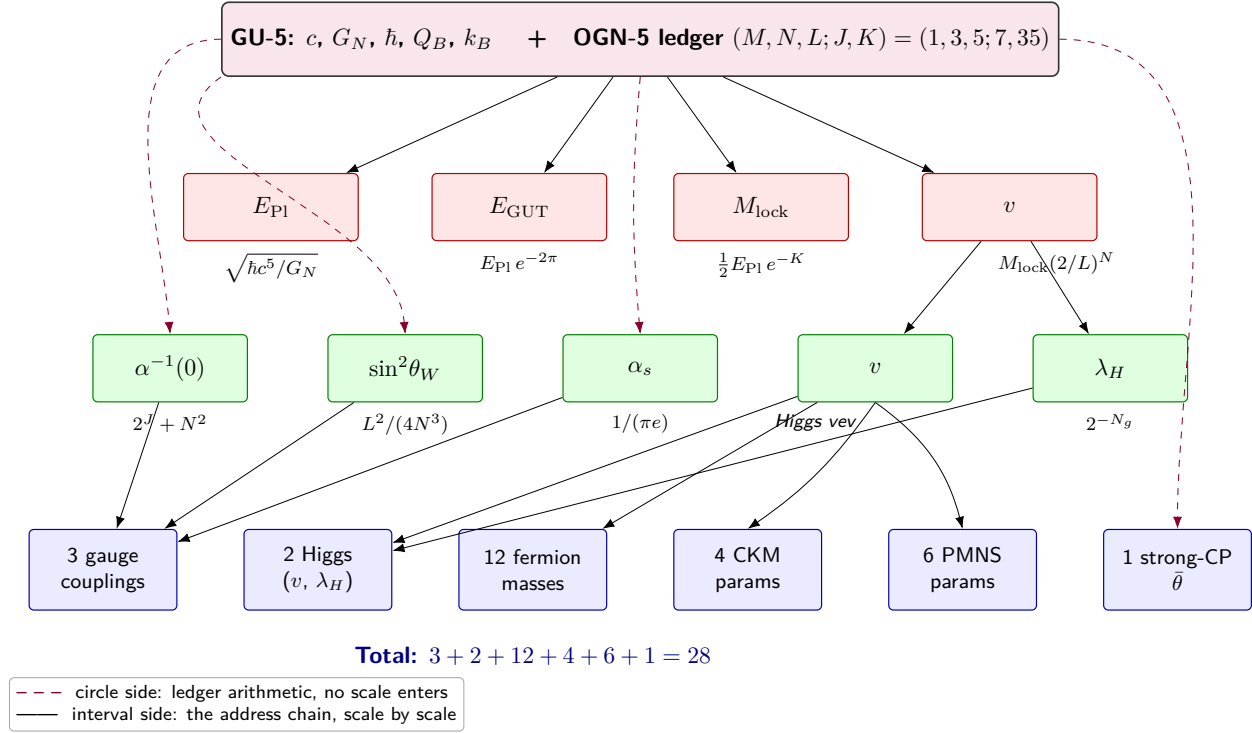


Figure 16: The codebook’s derivation tree (reproduced from Arisaka, 2026, A9-SM). Top: the five constants (GU-5, Arisaka, 2026, A4-Euclid) and the integer ledger $(M, N, L; J, K)$ (Arisaka, 2026, A2-GG6; Arisaka, 2026, A3-BI6). Second tier: the scale chain $E_{\text{Pl}} \rightarrow E_{\text{GUT}} \rightarrow M_{\text{lock}} \rightarrow v$ — the interval’s addresses, drawn with solid arrows because each one is reached from the one above it. Third tier: the five primary attractor coordinates. Three of them ($\alpha^{-1}(0)$, $\sin^2 \theta_W$, α_s) and the strong-CP angle are reached by *dashed* arrows straight from the ledger, because they are circle-side quantities: rational partitions and integer sums that no scale in the second tier can move. The remaining two (v , λ_H) descend from the address chain, which is why they carry units and the others do not. Bottom: the six buckets accounting for the twenty-eight Standard-Model parameters. Every arrow is a published derivation; no continuous freedom enters at any tier. This is Eq. (26) as an organism.

28.3 Reading the grammar: five worked entries

Plain-English walk-throughs of five entries, chosen to span the sheet; the full audit is the number table of §49 and the codebook’s own census.

- *The fine-structure constant.* $\alpha^{-1}(0) = 2^J + N^2 = 128 + 9 = 137$ at leading order: pure circle arithmetic — a dyadic power of the switch integer plus the color count squared — with the measured 137.036 reached by the codebook’s declared dressing. The most famous number in physics is spelled from two integers of the ledger.
- *The weak angle.* $\sin^2 \theta_W = L^2 / (4N^3) = 25 / 108 = 0.2315$ against the measured 0.2312: a rational partition — the circle dividing its own trace — not a running accident.

- *The electroweak scale.* $v = M_{\text{lock}}(2/L)^N = 246 \text{ GeV}$: the gearbox form — an interval depth ($M_{\text{lock}} = \frac{1}{2}M_{\text{Pl}}e^{-K}$) dressed by a circle fraction. The address explains the value; Problem 6 explains why no tuning was ever needed.
- *A fermion mass.* The quark floors take the form (winding label) $\times$ (radial overlap): which particle it is comes from the circle; how heavy it is comes from where its support sits on the interval. Identical particles have identical masses with no enforcement mechanism, because a label is a class and classes do not vary (Problem 8, Horizon 2).
- *A cosmological share.* $\Omega_m = 1/\pi$, $\Omega_b = 1/(2\pi^2)$: fiber volumes — the Hopf circle inside the electroweak three-sphere — so the “parameters” of the inventory are measures of the compact geometry, epoch-frozen (Problem 7).

The grammar also explains the sheet’s most puzzling texture: why some entries are precise integers and rationals while others sprawl across twelve orders of magnitude. The integers are labels (the circle does arithmetic); the sprawl is addresses (the interval does exponentials). One list, two fonts — and a century of attempts to derive the whole sheet in one font explains a century of partial success.

Figure 17 shows the sheet as the codebook reads it: one alphabet, two fonts, and no third column for dials.

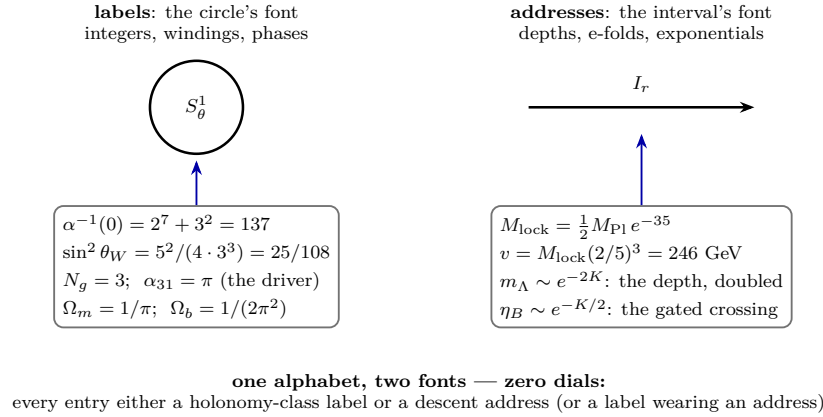


Figure 17: The sheet’s two fonts. A sample of the parameter sheet sorted the codebook’s way. Left: labels — pure ledger arithmetic, protected by the circle, unable to run. Right: addresses — depths on the interval, set by the descent. A parameter that looked like a dial for a century is a word in this grammar; the audit of Arisaka (2026, A9-SM) conjugates all twenty-eight.

The five entries above are a sample. Figure 18 shows the thirteen most sharply benchmarked entries of the sheet as the parent paper presents them — each closed form written in the ledger’s alphabet, beside the measured value and the fractional deviation (Arisaka, 2026, A9-SM). Nothing in the left-hand column was adjusted to reach the right-hand column; that is the whole of the claim, and the whole of the exposure.

28.4 How the sheet filled up: a two-paragraph history

The parameter sheet is the residue of a century of victories. Each revolution explained structure and deposited constants: quantum mechanics explained the atom and deposited $\hbar$ and the electron’s mass; the electroweak theory explained radioactivity and deposited the vev and the mixing angles; QCD explained the hadrons and deposited its coupling and quark masses; inflationary Λ CDM explained the sky and deposited its six-parameter

28 Free Parameters, One Geometry

Quantity	GG-6-Theory closed form	First order	Measured	Dev	Pull
Five primary gauge-Higgs attractor coordinates					
$\alpha^{-1}(M_Z)$	$2^J = 128$	128.0	127.930(8)	+5.5e-4	+0.99
$\sin^2 \theta_W(M_Z)$	$L^2/4N^3 = 25/108$	0.23148	0.23155(4)	-3.0e-4	-1.70
$\alpha_s(M_Z)$	$1/\pi e$	0.11710	0.1180(9)	-7.6e-3	-0.70
v [GeV]	$M_{\text{lock}} (2/L)^N$	246.33	246.220	+4.5e-4	+1.00
m_H [GeV]	$\sqrt{2\lambda_H} v, \lambda_H = 1/8$	123.12	125.10(9)	-1.6e-2	-0.95
Four derived electroweak observables					
G_F [10^{-5} GeV^{-2}]	$1/(\sqrt{2} v^2)$	1.1653	1.16638	-9.1e-4	-1.00
$\alpha^{-1}(0)$	$2^J + N^2 = 128 + 9$	137.0	137.036	-2.6e-4	-1.00
m_W [GeV]	$\frac{1}{2} g_2 v$	80.21	80.369	-2.0e-3	-0.99
m_Z [GeV]	$\frac{1}{2} v \sqrt{g_2^2 + g_Y^2}$	91.50	91.188	+3.4e-3	+1.01
Three charged-lepton masses					
m_e [MeV]	$(v/\sqrt{2}) N/(L^3 2^{J+L+1})$	0.51030	0.51100	-1.4e-3	-0.88
m_μ [MeV]	$(v/\sqrt{2}) L/2^{J+L+1}$	106.31	105.658	+6.2e-3	+0.98
m_τ [GeV]	$(v/\sqrt{2}) N_g J/2^{J+N_g+1}$	1.7861	1.77693	+5.1e-3	+1.09
Cabibbo angle (first CKM mixing)					
$\sin \theta_{12}^{\text{CKM}}$	$ e^{-\pi/2} - e^{i3\pi/5} e^{-\pi} $	0.22502	0.22501	+3.8e-5	+0.01

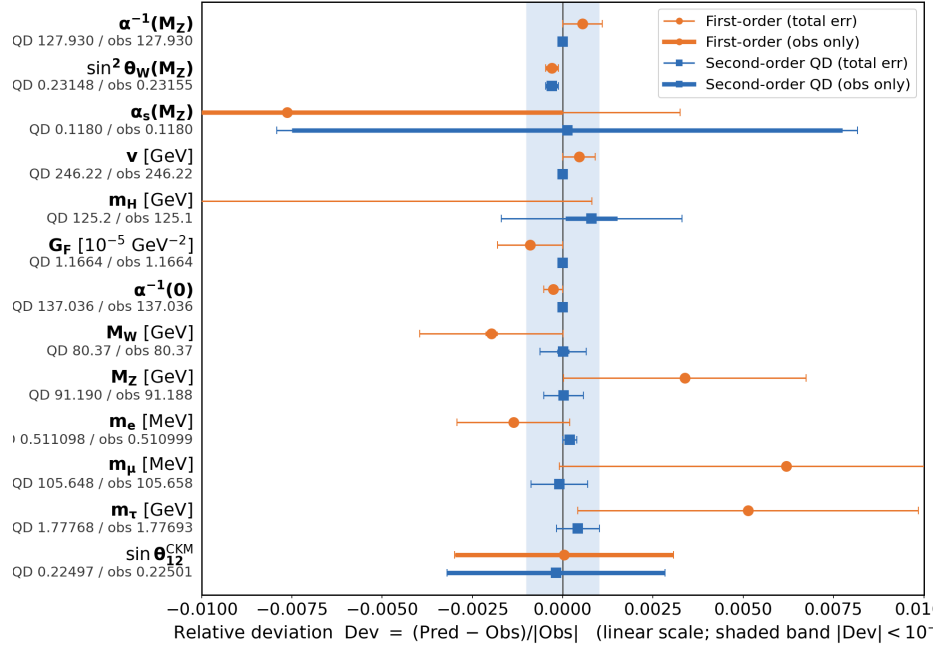


Figure 18: The thirteen most sharply benchmarked entries of the sheet (reproduced from Arisaka, 2026, A9-SM). Each closed form is written in the ledger’s own alphabet — the switch integer $J = 7$, the second entry $N = 3$, the lattice integer $L = 5$, the lock depth $K = 35$ — and set beside the measured value with its fractional deviation and pull. The two fonts of Figure 17 are visible by row: α^{-1} and $\sin^2 \theta_W$ are circle-side arithmetic, integers and rational partitions that cannot run; v and the lepton masses are interval-side addresses, a depth $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K}$ dressed by a circle fraction. The lower panel plots the same thirteen on a linear deviation axis at first and second order. No entry in the closed-form column contains a quantity fitted to the measured column.

concordance. The pattern was so steady it acquired a name — *effective field theory*: every layer’s constants are the next layer’s problem. The sheet, in other words, is not a scandal but a frontier marker: it records exactly where explanation stopped.

What changed the stakes was the failure of the expected next step. Grand unification derived a few relations and predicted proton decay — unobserved at the predicted rates; supersymmetry promised to relate the sheet’s halves — unfound at the LHC. The sheet stayed full, and the discipline’s response bifurcated: downward, into the landscape (the sheet is environmental, Problem 15), or inward, into the possibility this paper develops — that the sheet was never a list of constants at all, but a text in an unrecognized script.

28.5 The chain, worked end to end

The grammar is best displayed by walking one unbroken chain from the ledger to the laboratory, every step a published closed form. Start from the five integers, fixed by the anomaly audit of Problem 3: $(M, N, L; J, K) = (1, 3, 5; 7, 35)$, with the closure identities $K = LJ$ and $J = 2N + 1$ binding them. The chain, displayed as the cascade it is:

$$\begin{array}{ll}
 M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} = 3.849 \text{ TeV} & \text{the interval’s depth sets the lock,} \\
 v = M_{\text{lock}} \left(\frac{2}{L}\right)^N = 246.3 \text{ GeV} & \text{(measured 246.22): the circle dresses it,} \\
 \sin^2 \theta_W = \frac{L^2}{4N^3} = 0.23148 & \text{(measured 0.23122): the partition,} \\
 \hat{\alpha}^{-1}(M_Z) = 2^J = 128 & \text{(measured 127.93): the dyadic anchor,} \\
 \alpha^{-1}(0) = 2^J + N^2 = 137 & \text{(measured 137.036): the infrared end,} \quad (26)
 \end{array}$$

and the same integers, run through the cosmological sheet, return $\Omega_m = 1/\pi$ (Eq. (10)) and the base rung of the Kaxion’s cap ladder, $\Xi_{\text{cap}} = K$. Each line’s structure repeats the last: an exact integer expression (the circle’s font) evaluated at, or dressing, an exponential depth (the interval’s). One ledger, six measured numbers, zero dials — and the chain is the *same* chain at every step: label arithmetic setting structure, depth arithmetic setting scale. The reader who wants all twenty-eight walks the codebook (Arisaka, 2026, A9-SM); the reader who wants the audit walks §49.

28.6 The numerology objection, met head-on

A sheet of integer formulas invites the gravest charge in the business: post-hoc numerology — with enough integers and operations, any number can be dressed. The cohort’s defense is procedural, and worth stating because it is the difference between this Problem and its disreputable cousins. *First, pre-registration*: the closed forms are published with named kill conditions and dated instruments before the decisive measurements (the falsifier registry; §51) — numerology never volunteers to die. *Second, one alphabet*: the same five integers must serve every entry — each new closed form is a constraint on the same tiny ledger, not a fresh dip into the integer sea; the fits that numerology enjoys grow easier with each success, while this sheet grows *harder*. *Third, the flag register*: candidate patterns without mechanism (the $4K/8K$ family) are quarantined at flagged grade, cited as support never — a discipline numerology cannot afford. *Fourth, cross-exposure*: the same integers face colliders, haloscopes, and the CMB, with no shared systematics; a conspiracy of coincidences would need to span twelve orders of magnitude of experimental technique. The charge deserves to be leveled; the procedure is the answer.

28.7 The sheet’s decade: from measured to audited

The codebook converts the parameter problem from a lament into a schedule, and the schedule is running now. Each class of entry has its auditor: the collider cluster at 3.849 TeV audits the depth-arithmetic that anchors every mass address (§51); DUNE and Hyper-Kamiokande audit the flavor lattice’s sharpest letter ($\delta_{\text{PMNS}} = 196.4^\circ$ — a zero-parameter angle sitting in the experimentally favored quadrant); the haloscopes audit the ledger’s $1/K$ in a laboratory spectrum; the Simons Observatory and LiteBIRD audit the launch’s two outputs; and the precision-electroweak program continues to grind on the closed forms’ dressed digits. A decade of instruments, each reading a different row of one sheet — and the sheet’s grammar makes the audits mutually reinforcing in a way fitted frameworks cannot imitate: because every row spends the same five integers, each confirmation tightens all rows, and each failure indicts them all. The parameter problem’s endgame, on this reading, will not be a theoretical proclamation; it will be a decade of returned invoices, and the sheet is priced to be worth exactly what survives.

Figure 19 shows the audit’s current state — including, prominently, what is *not* yet derived.

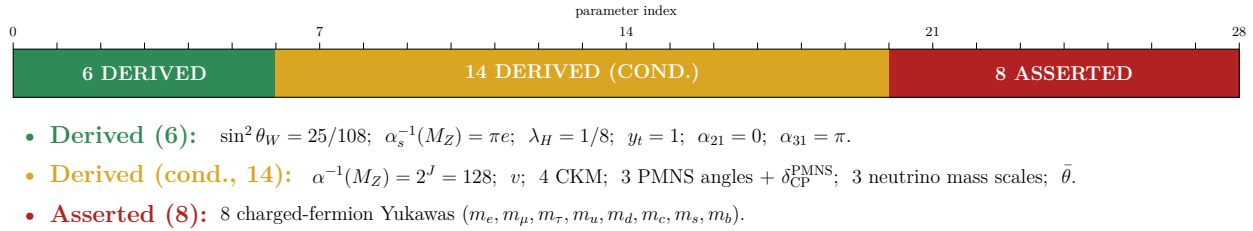


Figure 19: The 28-parameter audit at a glance (reproduced from Arisaka, 2026, A9-SM). Six parameters Derived outright (green), fourteen derived modulo a single named structural lemma each (gold), eight still Asserted with an explicit promotion roadmap (red). The honesty is the point: the codebook’s claim is not “all twenty-eight are theorems” but “all twenty-eight are *graded*, and the grades are public” — the difference between a codebook and a fit is that a codebook can show you which pages are finished.

28.8 What “no dials” buys, and what it costs

A dial-free sheet buys the strongest currency in science: exposure. A fitted framework meets an unwelcome measurement by adjusting; this construction can only be right or wrong. Every closed form above is separately falsifiable at precision, the comparisons span instruments with no shared systematics, and a single parameter that resists both the ledger arithmetic and the declared-input list kills the no-third-species claim outright — not wounds: kills. The cost is paid in the same currency: the framework cannot absorb surprises. The cohort regards the trade as the whole point, and its papers stake the calendar on it (§51).

What honestly remains is short, and the honest ledger of §47 lists it: the declared inputs (the scalar amplitude; the named joints of the η_B chain), the open integers (the Kaxion’s cap loading), the flagged candidates (the $4K/8K$ family), and the per-parameter grades of the codebook’s own triage — derived, derived-conditional, named — which this paper inherits and never promotes. Einstein’s hope, in this accounting, is neither achieved nor abandoned: it is *scheduled*, entry by entry, with the remaining freedom counted on one hand and each item owned by a named campaign.

Grade and kill, consolidated. Grades per parameter, inherited. Kill: distributed across the sheet — any closed form off its dressing; any parameter demanding a third species; the collider, haloscope, and CMB switches of §48 each audit a different row. The parameter problem, on the anatomy, was never a problem of too many numbers: it was one grammar, unread — *the sheet is a codebook, and the code is the two fibers*.

Part III in one paragraph, and what comes next

Four embarrassments of the Standard Model, one diagnosis. The measurement problem is two dynamics because there are two fibers: the circle carried the coherent phase, the interval wrote the outcome, and the two rules were never rivals. The four interactions look unlike because three of them are the circle's registration modes and one is the interval's agent. Gauge invariance is the circle's unreadability and renormalization is motion along the interval — which is why one is exact and the other flows, and why a century of trying to explain both in one language explained neither. And the parameter sheet is a codebook in two fonts: integers and rational partitions where the circle wrote, exponential depths where the interval did.

The same two fonts now spell the sky. Part IV takes the four questions cosmology cannot close — what launched the expansion, why the scales stand so far apart, what most of the universe is made of, and why regions that never met agree — and finds the interval doing the descending and the circle doing the keeping, in every one of them.

Part IV

Cosmology

Problems 5–8: the Beginning, Naturalness and Hierarchy, the Dark Trio, and the Three Horizons

The four problems of this Part are the ones a newspaper asks first: how did it start, why are the numbers so extreme, what is the dark stuff, and why is it the same everywhere. All four are developed below; Problem 7 carries the fullest quantitative apparatus.

29 Problem 5. The Beginning of the Universe

29.1 The oldest question, and its modern form

What happened at the beginning? The twentieth century converted the question from theology to physics and then discovered that its best theories resign at the door. Run general relativity backward and the singularity theorems promise a point where curvature diverges and the equations fail — not a description of the beginning, but a certificate that the description ends. Quantum-gravity programs soften the point but have not replaced it with a calculation matched to data. And inflation, for all its successes, made the initial-condition half of the question sharper rather than softer: the inflaton’s starting value, the patch that inflated, the pre-inflationary state — each is an input, and in the eternal-inflation reading the beginning recedes into an unending regress of beginnings. The modern form of the question is therefore double: *what replaces the singularity*, and *who chose the initial data*.

29.2 The question transformed: from “what banged” to “what launched”

On the anatomy, cosmic history is the one-way reading of the bulk (Problem 13): a descent along the interval, depositing on the boundary the letters stored on the circle. A reading has no detonation; it has an *opening*. The question “what banged?” presupposes an event in time; the anatomy replaces it with a structure in geometry — the top of the descent — and asks instead: *what launched the reading, and is the launch computable?* That question, unlike the original, has been answered in part: the launch is the interval’s coordinate rolling once down its derived plateau (Problem 7), with the e-fold count $N^* = 52.6$, the tilt $n_s = 0.9634$, and the tensor target $r = 0.0038$ computed rather than assumed, and the whole subsequent chronology — the straight line of Figure 38, closing its age ledger at 140.24 — following with no further input (Arisaka, 2026, A10-Cosmos). The Big Bang, in this reading, is not an explosion at a point but the top of a slide: hot because the roll’s energy reheated the boundary, uniform because one patch was stretched over the sky (Problem 8), and lawful from the first e-fold because the laws are the groove, not products of the fire. Figure 20 draws the transformation of the question.

29.3 Who chose the initial data: nobody

The second half of the question dissolves rather than resolves, and the dissolution is the determinism triad of §18 applied at the top. The standard framework needs initial data because its dynamics is reversible: every history is possible, so something must select ours. The descent needs none, in the precise sense that nothing

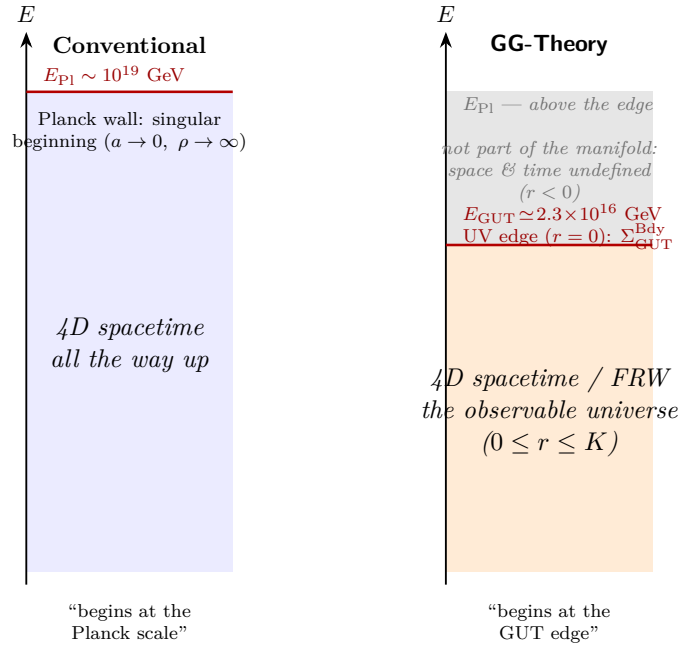


Figure 20: Where the universe begins (reproduced from [Arisaka, 2026, A10-Cosmos](#)). *Left:* the conventional picture — the description runs back to the Planck edge and ends in a singularity, so the beginning is where physics stops. *Right:* the anatomy’s picture — the descent begins at the GUT surface ($r = 0$, the top of the interval), the Planck scale is demoted to a unit of account above it, and the open item is an *entrance*, not a wall. The question changes shape before it is answered: not “what happened at the singularity?” but “what placed the coordinate at the top of the corridor?”

selectable remains: the vacuum dial is quantized with a unique scan winner, the landscape has one floor per admissible stratum (§18), and the compact angles are pinned coherently during the launch (§31.7) — so the “initial conditions” of every subsequent era are *outputs* of the reading, not inputs to it. The cohort calls this *determined initial data*, and its signature is that it over-predicts: a chosen-initial-data universe could not compute the zero-isocurvature null, the patch-uniform relic density, or the F25 statistical fossil (Problem 1) — a framework with freedom at the start has nothing to say about fossils of the start. This one stakes all three.

29.4 The Planck scale, demoted to a unit

Where in this is the Planck era — the quantum-gravity cauldron of the popular account? The anatomy performs a quiet demotion: the Planck scale appears in this paper’s chronology as a *unit* — the anchor t_{Pl} in which the age ledger is counted, the normalization M_{Pl} from which the descent’s addresses are measured — and not as an epoch the history must survive. The descent’s own account opens at the GUT-edge corridor, some three orders below Planck; nothing in the derived chronology requires physics at the Planck point itself, and the famous “first 10^{-43} seconds” is, on this bookkeeping, not a moment of the story but a rung of the address system. This is a genuine difference of framing with the standard account, and an honest one: the anatomy does not solve trans-Planckian physics; it declines to need it for anything it computes.

29.5 What inflation solved, and the bill it left

Honesty about the standard framework sharpens what is new here. Inflation solved real problems — flatness, horizons, the origin of structure — and its acoustic predictions are confirmed in detail. But its solutions were purchased on credit, and the unpaid items define the modern beginning-problem: *who chose the potential* (a functional freedom the census of Problem 7 closes); *who chose the starting point* (initial-data freedom, closed above by the determined data); *what came before the inflating patch* (the entrance, still open here too, but named and shaped); and *how to stop the recursion* — in generic potentials inflation is eternal, endlessly re-seeding, so that the theory’s late-time predictions drown in the measure problem. The anatomy’s launch pays these bills or names them: one potential (forced), one starting configuration (pinned), one traverse (a semigroup cannot re-seed — the once-only clause retires eternal inflation structurally, not by assumption), and one open item (the entrance), honestly carried. The comparison to the bounce and no-boundary traditions is structural: those programs seek to *continue* the geometry through or before the beginning; the anatomy’s descent instead *terminates* lawfully at an edge — the corridor’s top — and asks what boundary data the constitution puts there. Whether an edge or a continuation is the truth is exactly what the entrance item must decide; the anatomy’s contribution is to make it an item rather than a mystery.

Figure 21 draws the opening act: the plateau, the one roll, and the three observational windows staked on it. The mechanism deserves its equations, because they are the ones the sky has already graded. During slow roll the field φ (the interval’s coordinate, bent into a potential $V(\varphi)$) obeys the two smallness conditions

$$\epsilon = \frac{M_{\text{Pl,red}}^2}{2} \left(\frac{V'}{V} \right)^2 \ll 1, \quad \eta = M_{\text{Pl,red}}^2 \frac{V''}{V} \ll 1, \quad (27)$$

where V' and V'' are the potential’s first and second derivatives with respect to φ : ϵ measures the slope (how fast the roll steals energy from the stretch) and η the curvature (how soon the slope changes). While both are small the expansion is nearly exponential, and the number of e-folds accumulated between a field value φ and the roll’s end is

$$N = \frac{1}{M_{\text{Pl,red}}^2} \int_{\varphi_{\text{end}}}^{\varphi} \frac{V}{V'} d\varphi'. \quad (28)$$

The observables of Eq. (31) are these quantities evaluated at the moment today’s largest scales left the

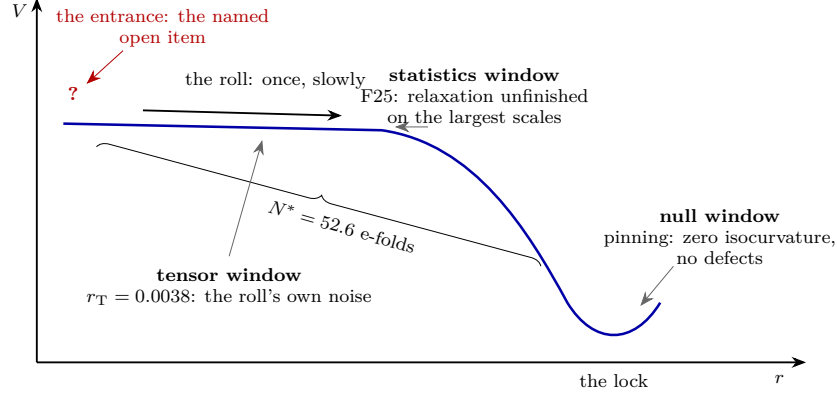


Figure 21: The launch, with its three windows. The plateau class is forced by the census; the roll is the interval's one traverse of its top, $N^* = 52.6$ e-folds; the entrance — why the coordinate begins on the high shoulder — is the cohort's named open item, marked honestly. Three instruments watch: polarization ($r_T = 0.0038$), large-scale statistics (the F25 relic), and the pinning's double null. A derived opening leaves derived fingerprints.

horizon: $n_s = 1 - 6\epsilon + 2\eta$ and $r = 16\epsilon$ in general, collapsing on the plateau class to the one-parameter forms $n_s = 1 - 2/N^*$ and $r = 12/N^{*2}$. The physical point: for a plateau potential the two measured numbers depend on *nothing* except how far from the end the observable window sits — which is why a derived $N^* = 52.6$ makes both numbers predictions rather than fits, and why the entrance (which fixes where the roll begins) is the one item the account still owes.

Figure 22 draws the standard mechanism as the textbooks give it, so that the one place this account departs from them is visible: not the slow-roll machinery, which is inherited whole, but the potential's shape, which here follows from the warp rather than from a choice, and the exit length N^* , which is a distance rather than a dial.

29.6 The first line of the ledger

The beginning, on the anatomy, has a number: the launch segment of the age ledger. From the Planck anchor to the end of reheating the clock advances $\ln(t/t_{Pl}) = 36.1$ — the plateau's $N^* = 52.6$ e-folds of stretch plus the reheating match at the derived T_{rh} , converted to clock e-folds (§36.5) — and everything observable about the era fits in three staked quantities: the tilt $n_s = 0.9634$ (the descent's length, read in the spectrum), the tensor target $r = 0.0038$ (the plateau's height, awaiting the Simons Observatory and LiteBIRD), and the zero-isocurvature null (the pinning's fingerprint). A beginning with a line in a ledger is a different *kind* of beginning from a singularity: it is an entry in the same audit as the rest of history — checkable, falsifiable, and continuous with the chronology of Problem 13 whose straight line it opens. The Big Bang, domesticated: not the edge of physics, but its first invoice.

29.7 The first second, hour by hour

Concreteness disciplines cosmogony, so walk the opening of the reading as the derived chronology actually schedules it (§36.6; all epochs from the one straight line of Figure 38). *The roll*: the interval's coordinate traverses its plateau — 52.6 e-folds of stretch, the sky's uniformity and its seed spectrum laid down together, the circle's ledger riding through untouched. *The exit*: slow roll fails; the holonomy variable's GSSB ends the episode (the circle's first word); the roll's energy reheats the boundary — the hot Big Bang begins as the

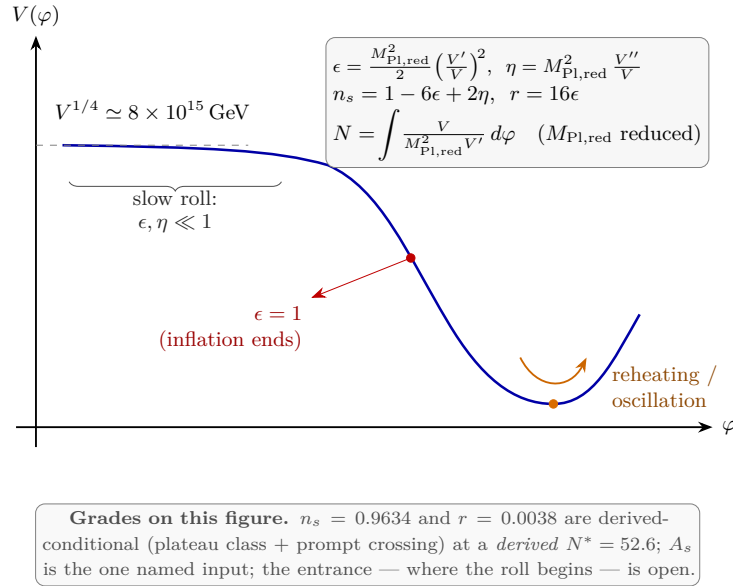


Figure 22: Slow roll, from the standard mechanism (reproduced from [Arisaka, 2026, A10-Cosmos](#)). The plateau potential $V(\varphi)$ with the three phases marked: the slow roll along the flat top (where Eq. (27)’s $\epsilon, \eta \ll 1$ and the stretch accumulates the N^* e-folds of Eq. (28)), the exit where the slope steepens and slow roll fails, and reheating — the oscillation about the minimum that converts the roll’s energy into the hot Big Bang. The plateau height is not a free label: with r staked at 0.0038 and $A_s = 2.1 \times 10^{-9}$ the one named input, the height follows, $V^{1/4} = M_{\text{Pl,red}}(3\pi^2 A_s r/2)^{1/4} \simeq 8 \times 10^{15} \text{ GeV}$ — some thirteen orders above the lock scale, and not a label the figure was free to choose. A tensor measurement is a measurement of this figure’s vertical axis. On the anatomy the horizontal axis is not an abstract field space: φ is the interval’s coordinate, the roll happens once, and the exit is the launch’s receipt.

launch’s receipt, at clock e-fold 36.1. *The lock* ($r = K$, $t \sim 10^{-11}$ s): the descent’s second saddle — the gate through which the heavy neutrino falls once, writing the matter excess (Problems 10–11), and the compact angle takes the displacement that will become dark matter (Problem 7). *The electroweak crossover*: the agent’s symmetry is read off the Wilson line; masses arrive at their addresses; shortly after, the sphaleron door welds, sealing the excess. *The QCD floor* ($t \sim 10^{-5}$ s): the triangle’s closure rule takes command; quarks weld into the guarded vaults of Problem 12; the Kaxion’s mass is delivered by the cooling susceptibility, and the circle’s coordinate begins to ring. One second in, the universe’s entire subsequent inventory — matter, dark matter, the sealed books — is on deposit, and everything since (nucleosynthesis at minutes, atoms at 380,000 years, structure at hundreds of millions) is the ledger compounding. The point of the itinerary is its *provenance*: every stop is a computed address on one line, not a bespoke epoch with its own theory — the first second is not a frontier of exotic physics but the busiest stretch of a single derived road.

29.8 Common misreadings, corrected

“The Big Bang was an explosion at a point.” Nothing exploded and there is no point: the launch stretched every region — space itself expanded everywhere at once — and “the beginning” names the top of the descent, not a location. The popular image fails exactly where the anatomy is sharpest: an explosion has a center and a before; a reading has an opening and a groove.

“Something must have come before.” *Before* is an interval word, and the interval opens at the corridor. Running the clock backward past the opening is not forbidden physics; it is unperformable bookkeeping — the semigroup has no inverse with which to run. Whether anything *terminates* the geometry at the top (an edge) or *continues* it (a deeper descent) is the entrance item, honestly open; what is already closed is that the question is structural, not temporal — there was never a “time before time” to narrate, only a corridor top to characterize.

“Quantum gravity must resolve the singularity first.” The derived history never visits a singularity: its account opens below the Planck point and its equations are regular everywhere they are used. Quantum-gravity physics may well govern the entrance — the open item is agnostic — but nothing this Problem computes waits on it. The beginning has been moved from the mercy of the hardest unsolved theory to the agenda of a named calculation, and that relocation is the Problem’s principal progress.

29.9 Watching the beginning: the three windows

“The beginning” sounds beyond observation; the launch is not, and its three windows are all staked. *The tensor window*: the plateau’s height fixes $r = 0.0038$, an order of magnitude above the design floors of the coming polarization missions — a detection near 0.004 would be, quite literally, an image of the opening stretch (primordial gravitational waves are the roll’s own noise); a null at those floors, or a detection near the current bound, kills the derived launch either way. *The statistics window*: the F25 fossil (Problem 1) — the largest scales retain the statistics the relaxation had not yet finished erasing, a direct sample of the pre-launch configuration that a free-initial-data cosmology cannot even formulate. *The null window*: zero axion-sector isocurvature and no defects — the pinning’s fingerprint, already holding, deepening with every CMB release. Three windows, three different instruments, one era: the beginning, on the anatomy, is not the least observable epoch but among the most — because a derived opening leaves derived fingerprints, and fingerprints are what instruments are for.

29.10 The entrance item, specified

Openness is only honest when it is specific, so the entrance’s requirements deserve their list — what any successful account of the corridor’s top must supply (Arisaka, 2026, A10-Cosmos): (i) the configuration at entry — why the interval’s coordinate begins on the plateau’s high shoulder, cold and smooth enough for the roll to proceed; (ii) the status of the pre-entry region — edge or continuation, and if an edge, the boundary data the constitution assigns there; (iii) the pinning’s execution — the reflection-symmetric dressing that freezes the compact angles during the roll, presently a named conditional, which an entrance account should derive; (iv) the budget — the e-fold accounting that would convert the $4K$ family (Problems 6–7) from flagged to derived, since the corridor’s total length is set at its top. Four requirements, one open item, and a definite shape: whoever closes the entrance closes, at a stroke, the deepest flagged numbers in the cohort — which is why it heads the queued campaigns, and why this Problem ends not with an apology but with a work order.

29.11 The entrance, honestly

What the anatomy does still owe is stated as the cohort states it. The derived launch begins at the top of the plateau; the *entrance* — the geometry’s own account of how the corridor is entered, the cold start before the first e-fold — is a named open item, with its requirements mapped and its candidate mechanisms cataloged but not closed (Arisaka, 2026, A10-Cosmos). This is the descent’s analog of the singularity question, and the honest boundary of this Problem: the anatomy has moved the frontier from “the equations fail” to “the corridor’s top is uncomputed,” which is progress of a specific, auditable kind — the open item has a shape, a location, and a list of what any solution must supply — but it is a frontier still. The reader should also notice what the anatomy makes of “before.” Along a semigroup, *before the first write* is not a place the formalism reaches by running backward — the fiber has no inverse transport — so whether the entrance question is a dynamical question (what process entered the corridor) or a boundary question (what conditions terminate the geometry) is itself part of what the open item must decide. The anatomy narrows the question; it does not yet answer it, and this paper says so.

Grade and kill, consolidated. The launch and chronology: derived-conditional (plateau class; prompt crossing). Determined initial data: the triad’s grades, with the pinning a named conditional. The entrance: open, named. Kill: the launch’s switches (r off 0.0038; $n_s < 0.955$); an axion-sector isocurvature detection (the lottery’s return); an F25-class fossil off its computed form. The beginning, on the anatomy, is not an event that escaped physics: it is the top of a groove — and the remaining mystery has been given an address.

30 Problem 6. Naturalness and the Hierarchy Problem

30.1 A forty-year anxiety

Two numbers have organized four decades of theoretical anxiety. The weak scale sits at 246 GeV while gravity’s scale sits at 10^{19} GeV — seventeen orders of magnitude apart — and in quantum field theory the light scale should not stay light: the Higgs mass receives corrections from every heavy threshold it couples to, so keeping it at 10^{-17} of Planck appears to require cancellations tuned to thirty-four decimal places. The vacuum energy is worse: its natural estimate exceeds the measured dark-energy density by some 120 orders. The response was a doctrine — *naturalness*: dimensionless ratios should be of order one unless a symmetry protects them — and a generation of protectors: supersymmetry pairing every particle with a canceling partner, compositeness dissolving the Higgs, extra dimensions lowering the true gravity scale. The doctrine was fruitful, the protectors beautiful — and the LHC, in the most consequential null result of the era, has

found none of them where naturalness said to look. The field now speaks openly of a naturalness crisis; the anthropic landscape (Problem 15) is one response; this Problem is another.

30.2 The anatomy’s answer: nothing is small; something is deep

The doctrine presupposed that a small dimensionless number is a *coincidence to be protected*. The anatomy replaces the presupposition: on the descent, a small number is an *address*. The weak scale sits where it sits because that is where the throat bottoms out:

$$M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} = 3.849 \text{ TeV}, \quad v = M_{\text{lock}} (2/L)^N = 246 \text{ GeV}, \quad (29)$$

thirty-five e-folds of descent with a ledger integer in the exponent, dressed by a circle fraction — the gearbox grammar of §19. The ratio $v/M_{\text{Pl}} \sim 10^{-17}$ is not a tuned cancellation; it is e^{-35} with bookkeeping — *counted, not tuned* — and the exponent is not adjustable, because $K = 35$ is a member of the anomaly-locked integer ledger (Problem 3). Exponentials of counted integers are what addresses look like; a civilization that measured only city distances would find the kilometer count between capitals “unnaturally large” by exactly this logic, and would be wrong in exactly this way.

30.3 The radiative half, reframed

The sharper half of the worry is stability: never mind the tree value — why do quantum corrections not drag the light scale up? The anatomy’s reframe has two clauses. *First*, corrections are interval-side flow: they move readings between addresses, and in the effective-theory organization the descent itself supplies, thresholds decouple as one descends — the flow redistributes; it does not pick the endpoint. *Second*, the endpoint is not balanced on a cancellation but pinned by structure: the lock is where the warp bottoms out, an integer depth, and the vev is its dressed image. There is no delicate difference of large numbers anywhere in Eq. (29) for corrections to upset. The doctrine’s silent premise — that the light scale is a fundamental parameter exposed naked to every threshold — is what the address grammar removes; with it goes the fine-tuning, and with the fine-tuning goes the need for protectors. On this reading the LHC’s null is not a crisis but a verdict correctly delivered: the protectors were guarding a problem the geometry never had. (The reading is falsifiable in the same breath: the same lock that dissolves the hierarchy *places a cluster at 3.849 TeV*, and its absence at staked sensitivity kills this Problem’s answer — §26.7.)

The anxiety has an exact source, worth displaying. Couple a scalar of mass m_H to a fermion of Yukawa coupling y (the top quark, $y_t \simeq 1$, dominates), and the one-loop quantum correction to the scalar’s squared mass is

$$\delta m_H^2 \simeq -\frac{3y_t^2}{8\pi^2} \Lambda^2, \quad (30)$$

where Λ is the highest scale at which the loop integral is cut off — the scale up to which the theory is trusted. The equation says the correction is set by the *cutoff*, not by m_H itself: if the Standard Model holds to the Planck scale, δm_H^2 is thirty-four orders of magnitude larger than the measured m_H^2 , and the bare parameter must cancel it to thirty-four digits. That is the hierarchy problem stated as arithmetic. The anatomy’s dissolution is equally arithmetic: the electroweak scale is not a small number surviving a large correction but a *deep address*, $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K}$ (Eq. (15)), and Eq. (30)’s Λ is not free: the descent supplies its own gauge-sector completion at the lock, so the loop’s reach — and with it the correction — is priced by the same $K = 35$ that sets the scale. Nothing cancels; something is far down.

30.4 The vacuum: the depth, doubled

The cosmological-constant hierarchy — the worst fine-tuning in physics — is the same answer squared. The terminus scale is the lock-scale seesaw, $m_\Lambda = M_{\text{lock}}^2/M_{\text{Pl,red}} \simeq 6.1$ meV: in e-fold form, twice the lock depth (e^{-2K}), so the vacuum density sits at roughly e^{-8K} of the Planck density — and the measured hierarchy is $8K$ to within 1.2% (§31.4). The honest register is repeated from Problem 7: the $8K$ face is *flagged* — the age ledger doubled, one observation wearing three faces, its would-be derivation the queued e-fold budget campaign — and nothing leans on it. What is not flagged is the structure: the meV scale arrives from the already-derived TeV scale with no new dial, and the “120 orders” dissolve into depth arithmetic whose one open coefficient is named, bounded, and *not small in its effect*: the derived terminus 6.1 meV stands against a measured $\rho_\Lambda^{1/4} = 2.24$ meV, so the drainage factor carries $\zeta_\Lambda^{1/4} = 0.37$ — a factor of 55 in density, uncomputed, and the reason this Problem’s vacuum-energy half is graded no better than the flagged half. The most notorious number in physics is, on this reading, the interval’s odometer — and an odometer reading is not a coincidence, however large.

Figure 23 replaces the cliff with the well: the hierarchy drawn as a depth gauge, with the four places the integer is spent.

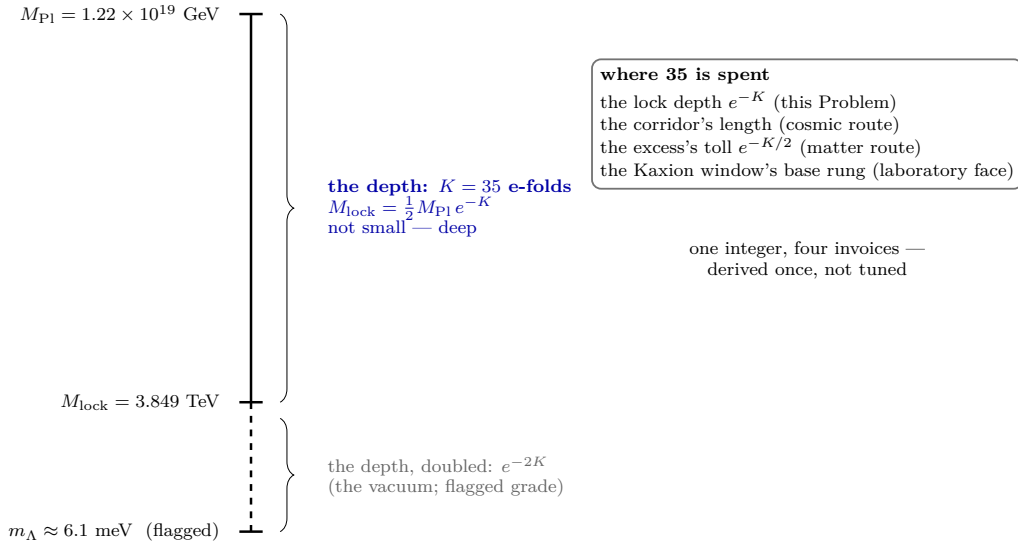


Figure 23: Nothing is small; something is deep. The seventeen-orders hierarchy drawn as what the anatomy says it is: a depth of $K = 35$ e-folds on the interval, with the electroweak address at the bottom of the well and the vacuum at the depth doubled (carried at flagged grade, never spent). The integer is derived once, from $K = LJ$ on an audited ledger, and then spent in four places that must all agree; a dial would be spent in one.

30.5 A short history of the anxiety

The doctrine has a genealogy worth one page, because each stage sharpened a true instinct. Dirac (1937) noticed the large dimensionless ratios of nature clustering near 10^{40} and its powers, and proposed — wrongly, it turned out, but fruitfully — that such numbers must be dynamical. Wilson and 't Hooft made the instinct precise: a small parameter is *technically natural* if a symmetry is restored when it vanishes — fermion masses are protected (chiral symmetry), the Higgs mass is not, and its unprotected smallness became *the* hierarchy

problem. Supersymmetry was invented, in large part, to be its protector, and for three decades the argument “naturalness $\Rightarrow$ new physics at the TeV scale” was the field’s best-subscribed prediction. The LHC then delivered the Higgs at 125 GeV — and, at staked luminosities, none of the protectors. The response spectrum runs from anthropics (Problem 15) to “naturalness was never a principle” to split and relaxion models; the shared premise of every response is that the small number is a *ratio of independent scales*. That premise is what the address grammar removes: on the descent the two scales were never independent — one is the other’s exponentially descended image, with an integer in the exponent. Dirac’s instinct was right after all, one inversion later: the large numbers *are* structural — not dynamical variables, but depths.

30.6 Why thirty-five

“Counted, not tuned” invites the next question: who counted? The exponent is not chosen to fit the hierarchy; it is the ledger integer $K = LJ = 5 \times 7$, and every factor in that product is fixed upstream by a step that can be checked. $L = 5$ comes from single-tensor Green–Schwarz consistency; $J = 2N + 1 = 7$ from the constitutional relation once N is known; and N from the anomaly audit’s dual-lock condition $L(2N + 1) = M^2 + N^2 + L^2$, whose roots at $L = 5$ are $\{3, 7\}$, with minimality selecting three (Arisaka, 2026, A2-GG6; Arisaka, 2026, A3-BI6).

It is worth being precise about what that chain is and is not, because a stronger-sounding claim is available and does not survive arithmetic. The dual lock is not a second, independent determination of K : setting LJ equal to $M^2 + N^2 + L^2$ is precisely the equation that selects N , and the resulting identity holds at *both* of its roots — $35 = 35$ at $N = 3$ and $75 = 75$ at $N = 7$. So K is derived once, along an audited chain, and not twice. What makes it hard to move is the other end: the same integer is *spent* four times over. The number that sets the weak-to-Planck ratio also sets, through the same ledger, the base rung of the Kaxion’s cap ladder ($\Xi_{\text{cap}} = K$, the window’s lower edge at 1.59 GHz), the corridor switch (e^7), and the throughput of the matter excess ($e^{-17.5}$) — one integer, audited at a collider, a haloscope, and the sky. This is what “the receipt” means concretely: a tuned number explains one measurement and predicts nothing; a counted depth is one column of a ledger whose other columns are already being checked.

30.7 Objections and replies

“You have traded a tuned ratio for a tuned exponent.” The exponent is an integer, and integers cannot be tuned — but the objection deserves its stronger form: could K have been *selected* to fit? The answer is no, and the reason has to be stated carefully, because one tempting version of it does not survive arithmetic. It is tempting to say that $K = 35$ is overdetermined by two independent routes, LJ and $M^2 + N^2 + L^2$. It is not. Setting those two expressions equal is precisely the dual lock that fixes N — with $M = 1$ it reduces to $N = L \pm \sqrt{L - M^2}$, whose roots at $L = 5$ are $\{3, 7\}$ — and the identity therefore holds at *both* roots, giving $35 = 35$ at $N = 3$ and $75 = 75$ at $N = 7$. The agreement of the two routes is the equation that selects N , not a second determination of K . A reader who checks this in four lines is right to, and the paper would rather print the check than be caught by it.

What survives, and it is enough: K is fixed *once*, by $K = LJ$, on a ledger whose members were fixed by the anomaly audit years before this Problem’s use of them; and the same integer is then *spent* in four independent places — the base rung of the Kaxion’s cap ladder, the corridor switch e^J , the excess’s toll $e^{-K/2}$, and the lock depth here. That is not overdetermination of K ; it is overdetermination of the ledger, which is the stronger claim anyway. A number spent on four watches cannot be quietly reset to fix a fifth.

“Why is there a throat at all — isn’t its existence the real tuning?” The warp is not installed to make hierarchies; it is the constitutional geometry of the fifth dimension (AX-2’s axiomatic

e^{-2r} profile, with its dynamical stabilization a named upstream item, carried honestly). The hierarchy is a consequence of the bulk the rest of the cohort independently requires — the same warp runs the chronology of Problem 13 and the seesaw of Problem 7. One geometry, many invoices: that is the opposite of a mechanism invented for one job.

“The little hierarchy: why is v fifteenfold below the lock?” By the circle’s dressing, $(2/L)^N = (2/5)^3 = 8/125$ — a fraction of ledger integers, not a small parameter. The factor’s smallness is arithmetic, its form is the gearbox grammar, and its audit is the vev’s own closed form sitting at 0.05% from measurement.

“Doesn’t the LHC null equally embarrass you at 3.849 TeV?” Not yet, and the difference is the point: the naturalness protectors predicted a *range* that has been progressively vacated; the lock predicts a *line*, with a fingerprint, inside the HL-LHC’s staked reach. One more null retires this Problem’s answer too — the exposure is symmetric, and the calendar is short. The anatomy does not ask to be excused from the standard it applies to the doctrine it retires.

30.8 Naturalness, retired with honors

The doctrine deserves a respectful funeral, because it was almost right. Its instinct — that unexplained small numbers signal missing structure — was sound, and led the field to genuine discoveries about symmetry and effective theory. Its error was the null hypothesis: it assumed the missing structure must be a *protector* (a symmetry holding a coincidence in place), when the anatomy supplies an *addresser* (a geometry in which the number was never a coincidence). Under MSMF the replacement is principled rather than opportunistic: the constitution forbids continuous parameters outright, so there is nothing in the theory *to* tune, and “unnatural” becomes a property no quantity of the framework can have — every number is an integer, a fiber measure, or an exponential address of integers. The naturalness question, on the anatomy, was never “why is the number small?” It was “what is the number’s address?” — and addresses are computed, checked, and, at 3.849 TeV, shortly to be visited.

Grade and kill, consolidated. The lock and vev: derived at codebook grades. The seesaw structure: derived; the $8K$ face: flagged. Kill: no cluster at 3.849 TeV at staked sensitivity (the direct visit); a measured $w \neq -1$ or phantom crossing (the terminus half); the e-fold budget campaign closing against the flagged family (its quiet death). The hierarchy problem, on the anatomy: *seventeen orders of magnitude is not a miracle; it is thirty-five e-folds — and the universe kept the receipt.*

The seesaw that dissolved the hierarchy left a residue — a vacuum energy of 6.1 meV, the square of the lock over the Planck scale. That residue is about to reappear as the third panel of the dark trio, which is the next Problem.

31 Problem 7. The Dark Trio: Inflation, Dark Energy, and the Kaxion

31.1 The census

The three great unexplained items of standard cosmology — what inflated, what the dark matter is, what the dark energy is — are, on the anatomy, answered by a *census* before they are answered by a computation (Arisaka, 2026, A10-Cosmos; Arisaka, 2026, C1-Kaxion). The bulk’s non-spatial sector contains exactly two coordinates. Both are promoted to boundary fields by OGGE. Both took the cosmic stage exactly once:

Inflation is the interval's coordinate, rolling once. Dark matter is the circle's coordinate, ringing still. Dark energy is what remains when both are at rest — its share written by the circle, its scale written by the interval.

The census also disposes of two famous embarrassments of riches in one stroke. The GDOS boundary law admits exactly one non-conformal scalar modulus — the radial stratum itself — so there is one candidate inflaton and no zoo; the compact sector supplies exactly two shift-protected angles with one light eigenstate, so there is one axion and no axiverse. *One interval $\Rightarrow$ one inflation; one circle $\Rightarrow$ one axion*: the scalar field content of cosmology is the dimensional census of the bulk.

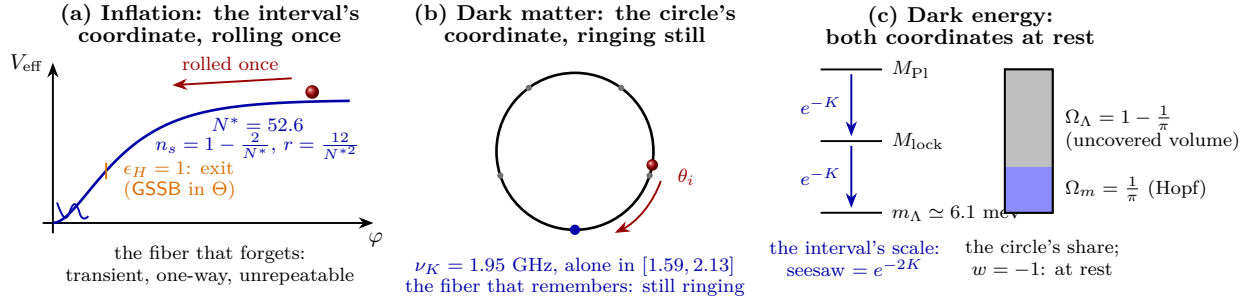


Figure 24: The trio on the two fibers (adapted from the cosmology companion (Arisaka, 2026, A10-Cosmos)). (a) The interval's coordinate rolls once along the warp-shaped plateau; $N^* = 52.6$ fixes the tilt and the tensor target; the exit is a GSSB in the holonomy variable Θ . (b) The circle's coordinate, pinned at θ_i , released once, ringing at 1.95 GHz and alone on a ladder of seven rungs. (c) Dark energy: the share is the circle's (the uncovered holonomy volume), the scale the interval's (the seesaw squares the descent); $w = -1$ is the semigroup at rest.

31.2 Inflation: the interval's coordinate, rolling once

The inflaton φ is the canonically normalized coordinate of I_r , and its episode wears the fiber's character (Arisaka, 2026, A10-Cosmos): a non-periodic plateau potential — the warp exponential $V \propto (1 - e^{-\sqrt{2/3}\varphi/M_{P1,\text{red}}})^2$, the e-folding of the descent bent into a potential — traversed *once*, ending when slow roll fails, unrepeatable because the fiber has no inverse transport. The observables are pure descent bookkeeping: the e-fold count $N^* = 52.6$ (undiluted — the lock crossing is prompt) gives

$$n_s = 1 - \frac{2}{N^*} = 0.9620 \quad (\text{measured } 0.9649 \pm 0.0042, \text{ pull } -0.7), \quad r = \frac{12}{N^{*2}} = 0.0043, \quad (31)$$

Both are leading-order readings of the same e-fold count; the exact values are $n_s = 0.9634$ and $r = 0.0038$ at $N^* = 52.6$. the tensor target several times above the projected $\sigma(r) \simeq 10^{-3}$ design floors of the Simons Observatory and LiteBIRD — a live kill switch, both directions. The circle appears at the boundaries of the act: the graceful exit is a GSSB in the holonomy variable Θ — *the circle's first word ends the interval's episode* — and the later lock crossing hands the compact angle the displacement that becomes the next act. Nothing quantized appears in inflation's output, and the anatomy says why: the interval has no holonomy to write with; the ledger rides through the launch untouched.

31.3 The Kaxion: the circle's coordinate, ringing still

Dark matter completes the triptych of matter portraits: *the electron is a holonomy class wearing a mass; the proton is two holonomy ledgers wearing a weld; the Kaxion is the holonomy coordinate itself, wearing an occupation* (Arisaka, 2026, C1-Kaxion; Arisaka, 2026, P3-Electron; Arisaka, 2026, P6-Proton). Everything it *is* is circle-side: two periodic parents (the tensor shadow and the holonomy echo), lightness by the circle's memory (a periodic direction admits no polynomial potential), a baryonic ledger entry locked at $-2/5$ by the anomaly audit — it couples only through topology because it is *made* of topology, which is the entire origin of its darkness — and universality by one pinned angle across the observable universe. Everything it *has* is interval-side: the Hubble-friction freeze, the once-only release when the circle's clock outruns the interval's ($3H = m_K$ at $T_{\text{osc}} \simeq 1$ GeV), the mass delivered by the cooling descent,

$$m_K = \frac{\sqrt{\chi_{\text{QCD}}}}{f_K} = 8.1 \pm 0.5 \text{ } \mu\text{eV}, \quad \nu_K = 1.95 \text{ GHz}, \quad \nu_K \in [1.59, 2.13] \text{ GHz} \quad (\Xi_{\text{cap}} \in [K, 47]), \quad (32)$$

and the relic abundance as the crossing's redshifted memory. Two credentials make it the campaign's cleanest exhibit: the dark-matter mass *is* the attractor's Hessian — a haloscope detection would be the first direct measurement of a GGA-class stability, the runtime's termination certificate heard as a tone — and its cascade is the only one in nature still finishing: caught mid-ring, the final GRIP-In of the observable universe. The search strategy is the anatomy's: *identify by the circle* (the discrete cap window, and the count: one line and no second), *search by the interval* (the GHz address).

Figure 25 draws the portrait this subsection has been building.

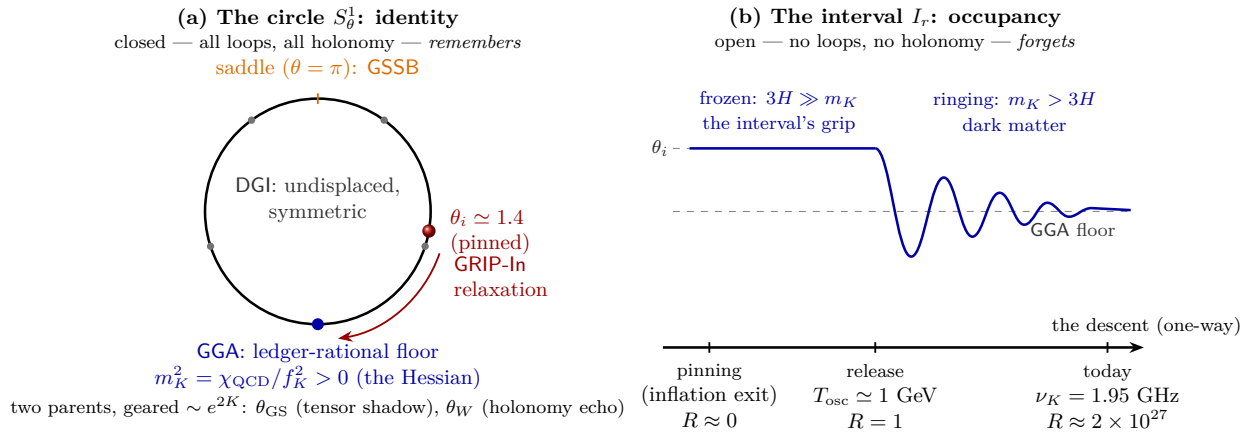


Figure 25: The Kaxion on the two fibers (reproduced from Arisaka, 2026, C1-Kaxion). (a) *The circle*: the Kaxion's identity — a compact-angle eigenstate on the pentagonal flavor lattice, its mass and couplings ledger arithmetic (Eq. (32)), protected because class data cannot drift. (b) *The interval*: the Kaxion's occupancy — the misalignment energy deposited at the lock crossing and diluted down the descent to today's halo density. Identity from the circle, abundance from the interval: the same two-fiber grammar as every particle in the cohort, which is why the haloscope strategy is to *identify by the circle* (the discrete cap window, and the count that puts one line in it) rather than merely to detect power.

31.4 Dark energy: both coordinates at rest

Dark energy's two numbers come from the two fibers, one each (Arisaka, 2026, A10-Cosmos). The *share* is the circle's: in the fiber-measure resolution, matter's fraction is the Hopf circle's volume inside the electroweak S^3 ,

$$\Omega_m = \frac{\text{Vol}(S^1)}{\text{Vol}(S^3)} = \frac{2\pi}{2\pi^2} = \frac{1}{\pi}, \quad \Omega_\Lambda = 1 - \frac{1}{\pi}, \quad \Omega_b = \frac{1}{2\pi^2}, \quad (33)$$

so the largest entry in the present energy budget is *the uncovered remainder of the holonomy volume* — epoch-frozen because fiber volumes do not dilute. The *scale* is the interval's: the lock-scale seesaw, in e-fold form an exact identity of the published chain,

$$\frac{m_\Lambda}{M_{\text{Pl,red}}} = \left(\frac{1}{2}\sqrt{8\pi}\right)^2 e^{-2K} \implies m_\Lambda = \frac{M_{\text{lock}}^2}{M_{\text{Pl,red}}} \simeq 6.1 \text{ meV}, \quad (34)$$

twice the lock depth: the seesaw squares the one hierarchy the interval ever wrote. The notorious 10^{-120} becomes an address — $-\ln(\rho_\Lambda/M_{\text{Pl,red}}^4) = 276.6 = 8K - 3.4$, and the de Sitter entropy is the same number inverted ($\ln S_{\text{dS}} = 278.9$) — carried at flagged grade, as the age ledger of Problem 13 *doubled*: one observation, three faces, all awaiting the e-fold budget campaign. And $w = -1$ exactly is the anatomy's sentence: *arrival at a terminus is irreversible on the fiber that cannot revisit* — a rolling quintessence would be a descent still in motion (transient by nature), and phantom crossing would be the semigroup running backward (never). The framework forbids both, and stakes it.

31.5 Why now

The coincidence problem — why the matter and vacuum densities are comparable in the present epoch — takes a sharpened form on the anatomy, and an honest answer. The crossover is a pure circle number read on the interval's clock: with both shares fixed as fiber volumes, equality sits at $z_{\Lambda m} = (\pi - 1)^{1/3} - 1 = 0.289$, no freedom anywhere. The residual question — why the observer's now falls within a factor of a few of that crossover — is the same question as the age ledger's $4K$ compression: *why does the odometer read ~ 140 e-folds when structure, chemistry, and observers arrive?* The cohort's answer is layered and carried at its layered grades (Arisaka, 2026, A10-Cosmos): the geometric facts (the crossover's location; the corridor's length) are exact; the timing of habitability within the corridor is bounded but anthropically read, and said so; and the would-be closure — the e-fold budget that would derive the whole clock face with no dial — is the campaign the cohort has queued, not claimed. The coincidence, on the anatomy, is neither a miracle nor an accident: it is one more reading of the one number this paper keeps meeting — the depth of the descent — and its final grade awaits the same derivation everything else in the flagged family awaits.

Figure 26 shows the inventory the census delivers — and shows it twice, because the static snapshot is the less interesting half of the story. Read the upper panel from left to right and the anatomy's division is drawn: the baryon:dark-matter split is *flat across the entire history*, a circle-side ratio $\Omega_b/\Omega_{\text{dm}} = 1/(2\pi^2) / (1/\pi - 1/2\pi^2)$ that was fixed once and cannot run; the matter:vacuum seam is the only thing that moves, and it moves because the interval is descending. One diagram, two fibers, and the π -locked inventory is simply the snapshot taken at the crossing.

The two panels are the same history on two clocks. The upper plots the density fractions Ω_i against cosmic time logarithmically, with the radial coordinate $r = \ln(E_{\text{GUT}}/\mu)$ carried on the second scale — the interval's own coordinate, running left to right, so that the horizontal axis of the figure *is* the descent this paper keeps invoking. The lower plots the same evolution in linear time, where the matter-to-vacuum handover stops looking like an event and becomes what it is, a gradual trade with the crossing magnified in the inset. Boxed in the upper panel are the ratios that never move: $\Omega_b/\Omega_m = 1/2\pi = 0.159$ and $\Omega_b/\Omega_{\text{dm}} = 1/(2\pi - 1) = 0.189$,

eternal because they are circle-side quantities and a circle-side quantity has nowhere to go. At the $\Omega_m = 1/\pi$ crossing — which falls some 75 Myr before today, close enough that the coincidence is worth asking about and far enough that it is not a tautology — the inventory reads $\Omega_\Lambda = 1 - 1/\pi = 0.682$, $\Omega_m = 1/\pi = 0.318$, $\Omega_b = 1/(2\pi^2) = 0.0507$, and $\Omega_{\text{dm}} = 1/\pi - 1/(2\pi^2) = 0.268$: fiber-volume ratios (Eq. (33)), not fits.

31.6 The triptych of matter, completed

The trio of episodes has a companion triptych of *objects*, and Problem 7 should close the pair. The cohort’s three portraits of permanence (Table 9).

Table 9: The three portraits of permanence, aligned. Each column is the subject of a cohort paper and each row asks the same question of all three: how the object stands to the circle (matter *on* it, matter *guarded by* it, matter *of* it); what fixes its identity (one ground basin, the double guard, one frozen angle); where its mass comes from (the descent’s terminus, the QCD floor, a susceptibility the descent delivers); what certificate the ground geometric attractor issues (no exit, no decay, a Hessian equal to m_K^2); and why each is inevitable rather than chosen — the ladder terminates, the weld closes, the displaced angle relaxes.

	Electron	Proton	Kaxion
Relation to circle	matter <i>on</i> it	matter <i>guarded by</i> it	matter <i>of</i> it
Identity by	one ground basin	the double guard	one frozen angle
Mass from	descent terminus	the QCD floor	$\chi(T)$, descent-delivered
GGA certificate	no exit	no decay	Hessian = m_K^2 : the line
Why inevitable	ladder terminates	weld closes	displaced angle relaxes

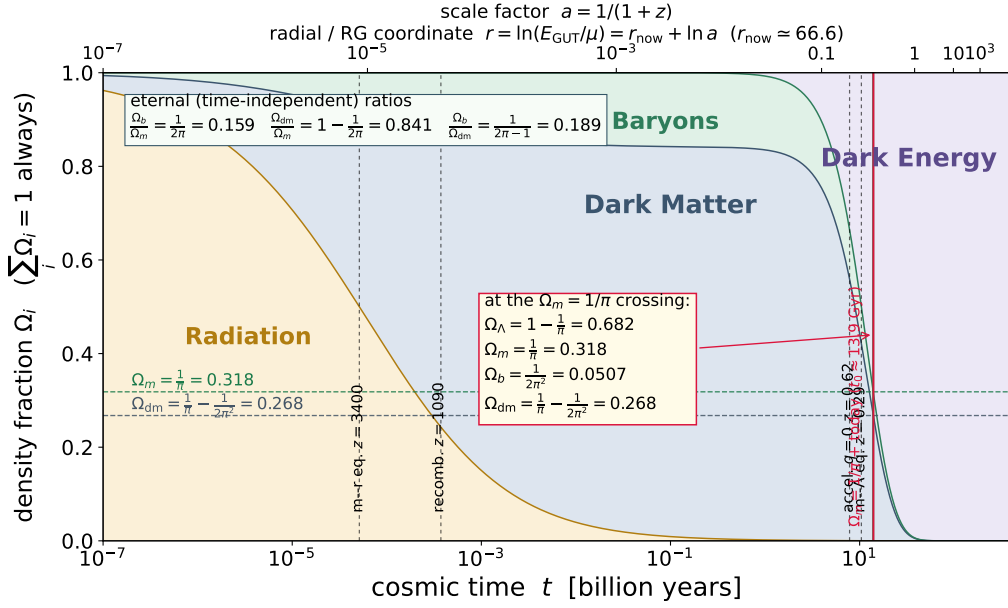
The electron is a holonomy class wearing a mass; the proton is two holonomy ledgers wearing a weld; the Kaxion is the holonomy coordinate itself, wearing an occupation (Arisaka, 2026, P3-Electron; Arisaka, 2026, P6-Proton; Arisaka, 2026, C1-Kaxion). The two triptychs interlock: the episodes (rolling, ringing, rest) are *how the descent spent its history*; the objects (labeled, guarded, ringing) are *what it deposited*. Between them they exhaust what a one-way reading of a chiral, integer-grooved tape can do — and the fact that the visible universe’s matter, its dark matter, and its vacuum are the three columns of one table is the anatomy’s quiet summary of cosmology.

One anatomy, four mechanisms. An alignment this neat invites a claim the paper does not make, so the claim is declined here rather than left to a reader to make on the paper’s behalf. The electron, the proton, the Kaxion and the late-time vacuum are not four outputs of one mechanism. The electron’s identity is a ground-state theorem on the GFF landscape, and it stands at the grade §18 prints for the floor’s uniqueness. The proton’s permanence is a winding class carried by a gauged $U(1)_B$, and §35.5 says in its own words that integrality alone forbids nothing and that the load is carried by the gauge law. The Kaxion is the circle’s own coordinate, given its mass by an interval-side freeze-out at the QCD floor. Dark energy is a fiber-volume ratio and a two-power seesaw: its *share* is derived, its *scale* arrives from an already-derived address with a drainage factor still uncomputed, and its 8K face is carried at *flagged* grade, which in this paper’s vocabulary (§22) means reproducible arithmetic with no mechanism yet, never used as support. Four objects, four mechanisms, four grades, and not one derivation shared among them.

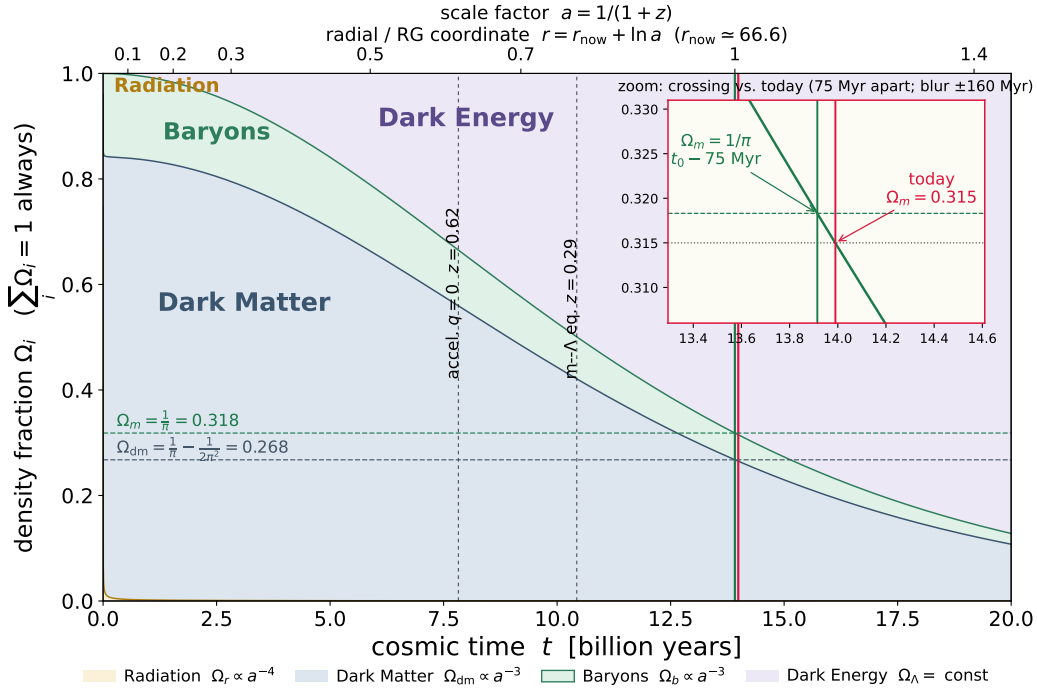
What *is* shared is the anatomy, and the sentence for it was written in Part II: *the circle states the alternatives, the interval performs the selection, the attractor is the circle’s receipt* (§12.2). Read across the four, that

The cosmic energy budget: the π -locked inventory is the $\Omega_m = 1/\pi$ crossing, 75 Myr before today

Bands always sum to 1 (flat universe). Only the matter: Λ split evolves; the baryon:dark-matter split is frozen for all time.



The same evolution in linear cosmic time: the matter $\rightarrow \Lambda$ handover, drawn gradually



— Radiation $\Omega_r \propto a^{-4}$ — Dark Matter $\Omega_{\text{dm}} \propto a^{-3}$ — Baryons $\Omega_b \propto a^{-3}$ — Dark Energy $\Omega_\Lambda = \text{const}$

Figure 26: The cosmic energy budget through history, shown twice (reproduced from Arisaka, 2026, A10-Cosmos; read panel by panel in the text opposite). Only the matter:vacuum seam moves. The upper panel runs on a logarithmic time axis and the lower on a linear one, so the same three shares — radiation, matter, vacuum — are shown once as a history and once as the present epoch a reader lives in. The two matter slices and the vacuum are fixed together by the π -locked inventory, which is why only one seam in the figure is free to move.

sentence says where each account’s parts live. The electron is a class on the circle; the proton is a winding of it; the Kaxion is its coordinate; the vacuum is its uncovered remainder. That is a claim about anatomy, not about derivation, and it is weaker than the sentence a reader is tempted to write — which is exactly why it can be checked, entry by entry, against the grades the parent papers print. The proton and the two dark entries carry dated instruments in §48; the electron’s account is exposed through the ledger all sixteen treatments share; and dark energy is listed here as the place the same anatomy is being taken next, not as a fourth result standing beside the other three.

31.7 The pinning, and the cleanest null in cosmology

The Kaxion’s patch-uniformity rests on a mechanism with an unusually clean observational face, and it deserves its own section because it is the trio’s sharpest near-term discriminator after the tensor target (Arisaka, 2026, A10-Cosmos; Arisaka, 2026, C1-Kaxion). In the standard axion story the initial angle is drawn at random in each causal patch: the relic density is an accident of our draw, and the field’s inflationary fluctuations imprint isocurvature perturbations that the CMB constrains — the story’s most dangerous bound. The descent replaces the draw with a pinning: during the primary inflation, a reflection-symmetric dressing pins the compact angle coherently across the entire future observable universe. Three consequences, each observable: *no lottery* (the relic density is deterministic — the $\theta_i \simeq 1.4$ of the abundance inversion is an output, not a draw); *no defects* (no patch-to-patch walls or strings from this sector); and above all *zero primordial isocurvature* — suppressed tens of orders below the Planck bound, so the constraint that hunts every random-draw axion passes here trivially. The signature runs both ways: a future *detection* of axion-sector isocurvature kills the pinning outright, and with it the trio’s middle panel. A null this deep, staked this plainly, is the anatomy’s preferred kind of prediction: the theory does not merely fit the absence; it *requires* it.

31.8 The trio, in one view

Figure 24 puts the three panels side by side, and the point of seeing them together is that they are one object in three states rather than three coincidences: the interval’s coordinate rolling once (inflation), the circle’s coordinate still ringing (the Kaxion at 1.95 GHz, alone in its window), and both at rest (the vacuum residue). Table 10 then sets the three side by side as a ledger — what each is on the anatomy, what it predicts, and the measurement that kills it — which is the form a reader should carry away, because the three kills are independent and a framework that survives all three has survived something.

Ninety-five percent of the present energy budget — dark matter plus dark energy — is the bookkeeping of the two non-spatial fibers, and the early universe’s defining episode is the open coordinate’s one traverse. *The dark sector is the two fibers, seen in the sky* — the becoming and the being, each showing up exactly once, and their joint silence accelerating the expansion ever after. Every number in this Part is falsifiable this decade, and Part VII collects the switches.

31.9 Seminar questions

What if the haloscopes sweep the window and find nothing? Then the trio’s middle panel dies as stated — the window is discrete (Ξ_{cap} ’s alternatives), not adjustable, and the cohort has pre-committed to that reading. What would survive is instructive: the census argument (one circle, one axion) is killed only if dark matter is found to be something a compact angle cannot be; a null without a replacement candidate kills the address, not the anatomy. The count is the discriminator either way, and it now runs in the opposite direction from the doublet it replaces: any line *with* a light QCD-coupled companion inside the window is not this framework’s Kaxion, however pretty its frequency. The discriminator is weaker for being a null — it is

Table 10: The cosmological triptych: rolling, ringing, rest. All entries published (Arisaka, 2026, A10-Cosmos; Arisaka, 2026, C1-Kaxion); grades inherited. The three columns are the interval’s coordinate rolling, the circle’s coordinate ringing, and both at rest: inflation for $N^* = 52.6$ e-folds once, giving $n_s = 0.9634$ and $r = 0.0038$; the Kaxion ringing since $T_{\text{osc}} \simeq 1$ GeV at $8.1 \mu\text{eV}$ and 1.95 GHz; and the de Sitter floor at $w = -1$ with $\Omega_\Lambda = 1 - 1/\pi$. The last row is what would kill each.

	Inflation	Dark matter	Dark energy
What it is	the interval’s coordinate, rolling	the circle’s coordinate, ringing	both coordinates at rest
Duration	transient: $N^* = 52.6$ e-folds, once	persistent: ringing since $T_{\text{osc}} \simeq 1$ GeV	eternal: $w = -1$, de Sitter
Key numbers	$n_s = 0.9634$; $r = 0.0038$	$8.1 \mu\text{eV}$; 1.95 GHz; one line in $[1.59, 2.13]$	$\Omega_\Lambda = 1 - 1/\pi$; $m_\Lambda \simeq 6.1$ meV against $\rho_\Lambda^{1/4} = 2.24$ meV, i.e. $\zeta_\Lambda^{1/4} = 0.37$ uncomputed
Why unique	one interval $\Rightarrow$ one inflaton	one circle $\Rightarrow$ one axion	both coordinates at rest $\Rightarrow$ one terminus (share derived; scale flagged)
Kill	r off 0.004 ; $n_s < 0.955$	isocurvature; off the $1.59\text{--}2.13$ GHz window	$w \neq -1$; phantom crossing

derived-conditional on the parents’ registered exposures rather than theorem-level, and this Problem carries it at that grade.

Could dark energy be slowly rolling after all? The framework forbids it and stakes the forbidding: $w = -1$ identically, no phantom side, with the conditions of the exactness theorem named. A confirmed $w(z)$ drift would not merely adjust a parameter — it would break the terminus reading (arrival is irreversible) and with it the anatomy’s account of why the descent ends. This is the trio’s cleanest theory-level exposure, and the survey instruments of the decade audit it continuously.

Is it a coincidence that all three episodes involve the same integer K ? It is the opposite of a coincidence — it is the point. $N^* = 52.6$ rides the corridor whose depth is K ; the Kaxion’s split is $1/K$ and its release toll rides $e^{-K/2}$ chains; the terminus’s seesaw is e^{-2K} . One integer, three sky-scale appearances, plus the collider’s e^{-K} — the trio is the strongest instance of the one-alphabet discipline of Problem 4, and the easiest place to kill it.

31.10 What the trio teaches the other problems

The dark trio is this paper’s best classroom because it is where the anatomy’s abstractions become inventory. *To Problem 5* it supplies the opening act and the fossil windows; *to Problem 6*, the seesaw that doubles the depth; *to Problem 8*, the stretch that buys Horizon 1 and the pinning that closes Horizon 3’s last lottery; *to Problem 14*, the terminus as the currency system’s closing statement; *to Problem 15*, the zero-isocurvature null that scores the draw-versus-groove question; *to Problem 16*, the de Sitter horizon as the paradox’s cousin. Six problems borrow from this one — which is the anatomy’s recursive signature throughout the paper: the answers are not sixteen separate keys but one keyring, and the trio is where the ring is easiest to hold.

32 Problem 8. The Three Horizon Problems

32.1 Three agreements, one puzzle

Point two radio telescopes at opposite edges of the sky. The microwave background arriving from each direction left its source before those regions could ever have exchanged a signal — and yet the two temperatures agree to one part in a hundred thousand. That is the textbook horizon problem, and inflation is its textbook solution. But the sky’s agreement runs far deeper than temperature, and the deeper layers are rarely posed as problems at all — they are assumed. Every distant galaxy is built of electrons with *exactly* the mass and charge of ours; every spectral line, at every redshift, is our line shifted and nothing else. And every region made the same *choices*: matter over antimatter everywhere (no annihilation glow at any domain boundary, anywhere); the same vacuum, the same broken symmetries, the same flavor textures. Three agreements, of escalating strangeness: the same *conditions*, the same *things*, the same *decisions*. Inflation addresses the first. What addresses the other two? The standard framework’s honest answer is: nothing — they are written into the assumption that “the laws of physics are the same everywhere,” which is not an explanation but the name of the mystery.

First, the puzzle’s arithmetic, so its size is on record. The particle horizon at last scattering — the farthest distance a signal could have traveled by $z \simeq 1090$ — subtends about 2° on today’s sky, so the microwave sky comprises

$$N_{\text{patch}} \sim \frac{4\pi}{(2^\circ)^2} \approx 10^4 \quad (35)$$

regions that, on the unstretched account, share no causal past — yet their temperatures agree to $\Delta T/T \sim 10^{-5}$, their contents to every measured digit, and their constants absolutely. Inflation repairs the first agreement by rewriting the denominator: the stretch makes the whole sky descend from one pre-inflation patch. The second and third agreements are what this Problem is about, because they concern choices made *after* any stretch.

32.2 Horizon 1: the same conditions — bought by the launch

The first horizon is the interval’s purchase, and the anatomy keeps inflation’s textbook answer while sharpening its status. The launch (Problem 7) stretches a single causally connected patch across the whole observable sky: uniform temperature, uniform curvature, and the seeds of structure laid by one coherent episode. What the anatomy adds is the census discipline — one interval, one inflaton, no menu — so the solution is not one scenario among hundreds but the unique roll the geometry possesses, with its two predictions ($n_s = 0.9634$, $r = 0.0038$) exposed. What it subtracts is the regress: the roll happened once, on a fiber with no inverse transport, so there is no eternal self-reproduction multiplying beginnings (§31.2). One patch, one stretch, one sky.

32.3 Horizon 2: the same things — bought by the classes

The second horizon is the circle’s purchase, and it needs no signal at all. Why is an electron at redshift six identical to an electron in this room? The standard framework must posit it: in field-theory language all electrons are excitations of one field, but *why the field’s parameters are position-independent* across super-horizon distances is again assumption. On the anatomy, identity is a holonomy class — charge a winding, spin and representation labels of the compact fiber — and *classes are the same everywhere without communication*: two regions need never have exchanged a photon for their windings to be equal integers, any more than two distant triangles need to correspond to both have three sides. Topology is the one kind of sameness that requires no synchronization, no mechanism, and no common past — which is precisely the

kind the sky exhibits. The labels' *addresses* (the masses) are equally uniform because the descent's landscape is the same groove read at every point (Horizon 3). One sentence: *the universe agrees about its contents because contents are classes, and classes cannot disagree.*

32.4 Horizon 3: the same choices — bought by the groove

The third horizon is the deepest, and it is the determinism triad of §18 projected across the sky. Wherever a symmetry broke, every region fell the same way: the same vacuum angle, the same flavor lattice, and — most tellingly — matter over antimatter with the same one-in-a-billion excess to the precision of nucleosynthesis. In any framework where those choices are spontaneous in the textbook sense — a random fall from a symmetric hilltop — causally disconnected regions *must* choose independently, and the sky should be a patchwork of domains with defect walls between them. It is not. The anatomy's three mechanisms close the lottery: the dial is quantized with a unique scan winner (nothing continuous to fall through), the GFF floor is unique per admissible stratum (nowhere else to land, by Frankel–Atiyah; §18), and the reading is one-way (no region can revise). Every region plays the same groove because there is one groove and the players cannot improvise. The sharpest instance is the excess itself, computed in Problems 10–11 and uniform wherever nucleosynthesis has been checked; the full development, with the tuning and lottery alternatives priced against the sky, is §34.7.

Figure 27 draws the puzzle and its three-part answer in one frame.

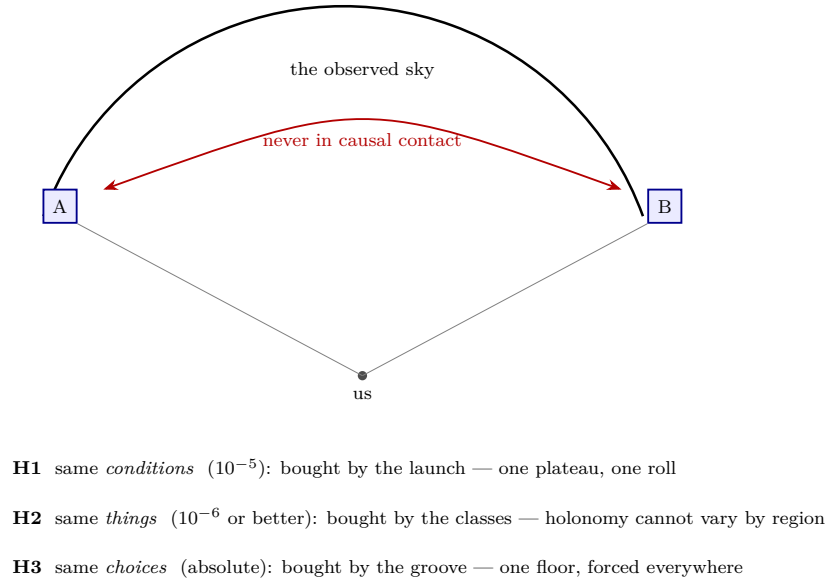


Figure 27: The three horizon problems, one geometry. Patches A and B share no causal past, yet agree in conditions, in kinds, and in constants. The stretch alone buys only H1; H2 is the circle's — classes are global data, with no local dial to drift — and H3 is the groove's, the floor of the determinism triad, unique on admissible strata. Escalating strangeness, one anatomy.

Figure 28 shows the standard diagram of the first horizon and its repair — and its silence on the other two.

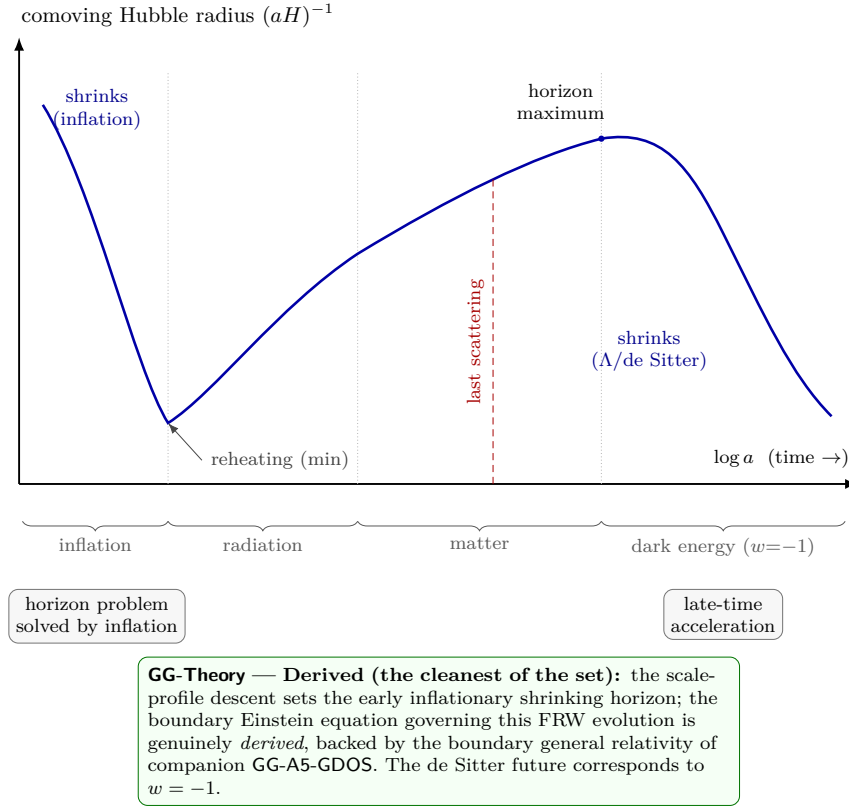


Figure 28: The horizon problem, and inflation’s repair, in the standard diagram (reproduced from Arisaka, 2026, A10-Cosmos). The comoving Hubble radius $(aH)^{-1}$ — the size of a causally coherent region, in comoving units — across the four eras. During inflation it *shrinks* through N^* e-folds: today’s largest scales exited a causally connected region early, and re-entered — through the radiation and matter eras, where the radius grows — carrying its uniformity; in the dark-energy era it shrinks again. Without the inflationary segment the radius only grows, and Eq. (35)’s patches never spoke. The repair buys Horizon 1 — shared conditions — and nothing else: the diagram is silent on why the patches’ particle *kinds* and *constants* agree, which is Horizons 2 and 3.

32.5 The alternatives, priced

Three accounts of cosmic sameness are on the market, and they separate observationally. *Tuning*: the sameness is an initial condition — but a tuned universe must tune every region separately, and pays the full improbability once per horizon volume. *The lottery with inflation as courier*: choices were made once in a tiny patch and inflated outward — this works for Horizon 1 and for any choice made *before* the stretch, but every post-inflationary breaking (the QCD angle, the electroweak vacuum, the axion misalignment of the standard story) reopens the lottery afterward, patch by patch; the standard axion’s isocurvature problem is exactly this reopening. *The groove*: nothing was ever drawn, before or after — same dial, same floor, same reading everywhere, at every epoch. The three accounts stake different skies: tuning predicts nothing and explains nothing; the courier predicts residual patch-variation in every late choice; the groove predicts *zero* — no domains, no defects from these sectors, no axion isocurvature, no drifting constants — nulls so deep they are signatures (§31.7).

32.6 The sameness, audited in numbers

The three horizons are quantitative facts before they are puzzles, and the numbers set the bar any explanation must clear. *Conditions*: the CMB temperature is uniform to $\Delta T/T \sim 10^{-5}$ across the full sky — across regions separated, at emission, by dozens of naive horizon lengths. *Things*: quasar absorption spectra constrain any variation of the fine-structure constant across billions of light years and billions of years at the part-per-million level; molecular and nuclear constancy bounds reach further; every extragalactic spectrum ever taken is our atomic physics, redshifted. *Choices*: the gamma-ray sky shows no annihilation seam at any scale — antimatter domains are excluded out to cosmological volumes; helium and deuterium abundances match one baryon-to-photon ratio everywhere nucleosynthesis can be probed; and no domain wall or sameness-breaking defect has ever been seen. Sameness at 10^{-5} , 10^{-6} , and absolute — three escalating precisions for three escalating depths of agreement. An account that buys only the first with dynamics and posits the rest has explained the least demanding third of the data.

32.7 What the stretch alone cannot buy

It is worth being precise about why Horizon 1’s solution does not extend, because the gap is the Problem. Inflation synchronizes whatever exists *before* the stretch; it is powerless about choices made *after*. And the standard framework makes its deepest choices after: the QCD vacuum angle settles at the QCD scale; the standard axion draws its misalignment angle at the Peccei–Quinn scale, patch by patch; in generic settings even the electroweak vacuum’s alignment is a post-inflationary event. Each late choice re-opens the lottery inside the stretched patch — the standard axion’s isocurvature and domain-wall problems are the textbook symptoms — so the courier account predicts residual patchiness in every late-deciding sector, at levels the searches keep pushing down. The groove differs precisely here: its choices were never events, early or late — the dial, the floor, and the reading are the same at every point because they are arithmetic, not history. The observational separation is therefore clean and current: every deepening null (isocurvature, domains, drifting constants) moves probability from the courier to the groove, and a single confirmed patch-variation moves it all back.

32.8 The identity recursion: sameness all the way up

Horizon 2’s class argument compounds through structure, and the compounding is worth exhibiting because it is where cosmic sameness touches everyday life. Identical electrons and identical protons (the classes) make identical atoms — every hydrogen atom in every galaxy has exactly our Lyman series, which is why redshift

surveys work at all. Identical atoms make identical chemistry: the periodic table is not a local convention but a holonomy consequence, the same table wherever matter has settled (Problem 12's biosphere section carries the argument into biology). Identical chemistry makes calibratable astrophysics: standard candles are standard *because* type-Ia detonations run on the same nuclear ledger everywhere — the entire distance ladder, and with it observational cosmology itself, quietly rests on Horizon 2. The recursion's summary: the universe is not merely made of the same stuff; it is *legible* — and legibility is the anatomy's deepest observational gift, because a cosmos of drifting classes could not even be measured coherently, let alone explained. The sameness the three horizons name is the precondition of the science that names them.

32.9 The observational faces

Each horizon carries live instruments. *H1*: the CMB's uniformity and its acoustic structure — long confirmed — plus the launch's own switches (r , n_s). *H2*: spectroscopic constancy — quasar absorption lines bound any spatial or temporal drift of the fine-structure constant at the 10^{-6} level and below, and every improvement is a sharper audit of class identity; a confirmed spatial variation of a protected constant would break this horizon outright. *H3*: the antimatter-domain searches (no annihilation edge in the gamma-ray sky), the defect searches (no walls, no cosmic-string signatures from these sectors), and the axion-sector isocurvature bound — the standard lottery's signature, whose continued null is the groove's fingerprint and whose detection is this Problem's kill. Three horizons, three nulls, all holding: the sky, so far, plays one record.

Grade and kill, consolidated. *H1*: the launch's grades. *H2*: theorem (class identity), audited by constancy bounds. *H3*: the triad's grades, with the pinning a named conditional. Kill: patch variation of a protected quantity; an annihilation edge; a domain wall; axion-sector isocurvature. The three horizon problems, on the anatomy, are one question asked at three depths — *why is it all the same?* — with one answer at three registers: *one stretch, one alphabet, one groove*.

Part IV in one paragraph, and what comes next

Cosmology, read on the two fibers, is one descent and one set of books. The launch is the interval's single traverse, which is why there is one inflaton and not a menu, and why $N^* = 52.6$ comes out as a length rather than a fit. The hierarchy is not a small number but a deep one: thirty-five e-folds down a throat, with the exponent a ledger integer. The dark sector is the two fibers in the sky — the interval rolling once, the circle still ringing at 1.95 GHz, and the vacuum the residue of both at rest. And the horizon problems are one question at three depths, answered by one stretch, one alphabet, and one groove.

Cosmology spent the fibers. The next Part asks what they are made of. Part V takes the four questions underneath matter itself — why the mirrors break and one does not, where the antimatter went, why quarks are never seen and the proton never dies — and finds the circle owning the orientations and the ledgers, the interval owning the amounts and the once-only crossing.

Part V

Foundation of Particle Physics

Problems 9–12: Discrete Symmetry, Antiparticles, the Excess of Matter, and Confinement
with the Stable Proton

The four problems of this Part are the discipline’s oldest foundations, and all four are treated at full length — they are the campaign’s original heartland. Problem 9 is the discrete symmetries; Problems 10 and 11 share one block (the mirror reading and the one-way toll are one story); Problem 12 is the guarded proton.

33 Problem 9. Discrete Symmetry: C , P , T , CP , CPT — and the Strong-CP Problem

33.1 The five operations, located

In the textbook presentation, the discrete symmetries are operations on fields: charge conjugation C swaps particles with antiparticles, parity P reflects space, time reversal T runs the film backward, and the celebrated theorems — CPT exactness, CP violation — arrive as properties of Lagrangians. The two-fiber anatomy relocates all five *into the geometry*: each discrete operation is the reversal of an orientation that the bulk actually possesses, and each observed fate — exact, broken, or broken-at-runtime — follows from *which fiber owns the orientation being reversed* (Arisaka, 2026, P5-CPT; Arisaka, 2026, P4-Real).

The bulk offers exactly three orientations: the compact circle S_θ^1 can be traversed in two senses; the constitutional clock — the causal orientation of the boundary, tied to the interval’s one-way descent — can be assigned in two senses; and the spatial stage $\mathcal{M}_4$ can be given either handedness. The dictionary is then one line each (Table 11).

Table 11: Which structure each discrete operation reverses, and which part of the geometry owns it. C reverses the sense of the circle, $\theta \mapsto -\theta$, and belongs to the sixth dimension; P reverses the handedness of the spatial stage and belongs to $\mathcal{M}_4$; T reverses the sense of the clock and belongs to the causal orientation the interval feeds. CP is therefore mixed, turning circle and stage together, and CPT reverses all three orientations at once — which is why it is a property of the total geometry rather than of any single fiber.

Operation	What it reverses	Owning structure
C	the sense of the circle, $\theta \mapsto -\theta$	S_θ^1 (the 6th)
P	the handedness of the stage	$\mathcal{M}_4$
T	the sense of the clock	the causal orientation the interval feeds
CP	circle and stage together	mixed
CPT	all three orientations at once	the total geometry

Nothing here is new dynamics — the identifications are the CPT companion’s theorems T-P5-A/B/C (Arisaka, 2026, P5-CPT) and the real-bulk companion’s discrete-symmetry table, derived from the orientations of

its two global structures, the circle and the clock (Arisaka, 2026, P4-Real). What the anatomy adds is the explanation of the *fates*.

The claim in symbols. Write θ for the phase circle’s coordinate, x for the stage’s spatial directions, and t_b for the boundary clock. The three operations are the three independent orientation reversals the geometry offers:

$$C : \theta \mapsto -\theta, \quad P : x \mapsto -x, \quad T : t_b \mapsto -t_b, \quad (36)$$

— charge conjugation reverses the circle’s winding sense (which negates every charge, since charges are windings), parity reverses the stage’s handedness, and time reversal reverses the clock against which the runtime reads. Their product CPT reverses the total orientation of the bulk, and a total orientation reversal is an isometry of the geometry itself: nothing in any fiber can distinguish the two senses jointly. That is the anatomy’s one-line proof sketch of what the Lüders theorem establishes from field axioms — and its explanation of the pattern: each *single* reversal can fail wherever some structure fixes a preferred sense (the chiral alphabet fixes the circle’s, the runtime fixes the clock’s), but the *joint* reversal has no structure left to notice it. The laboratory numbers this section must answer to: the observed CP violation in kaons at 2×10^{-3} , direct T violation (Lees et al., 2012), and the strong- CP bound $|\bar{\theta}| \lesssim 10^{-10}$ from the neutron electric dipole moment (Abel et al., 2020).

33.2 Why CPT is exact

CPT reverses every orientation the geometry has. A world read with all orientations flipped is the same geometry described in the mirror convention: the holonomies are conjugated, the descent is relabeled, and no invariant changes. Formally, the real-bulk construction makes CPT the automatic composite — the one discrete operation that is a symmetry of the *books* and of the *reading* at once — which is why its exactness is not an assumption of the framework but a consistency statement: breaking CPT would require the bulk to possess a fourth orientation it does not have. The laboratory statement inherits the geometry’s confidence: any observed CPT violation — a mass difference between a particle and its antiparticle, at any precision — falsifies not a model choice but the arena itself.

Figure 29 draws the three reversals on the geometry.

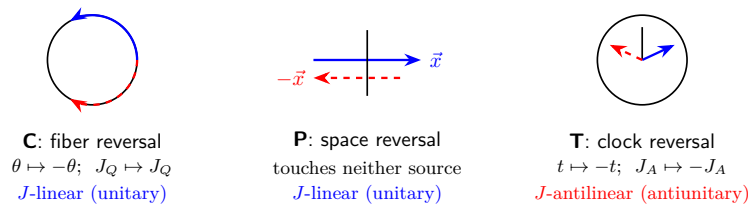


Figure 29: The three orientation reversals (reproduced from Arisaka, 2026, P5-CPT). Each panel reverses one sense of Eq. (36): C the circle’s winding (all windings $\mapsto$ their negatives, so every charge flips while masses — which are not orientations — stay fixed), P the stage’s handedness, T the clock’s direction (under which the runtime’s currents reverse). A discrete symmetry “breaking” is, on this reading, never dynamical: it is the presence of a structure that fixes one of the three senses — and the table of fates in this section is the census of which structures exist.

33.3 Why CP breaks: the chiral alphabet

C alone and CP are symmetries of the connection but not of the *content* written on the circle. The flavor sector deposits on S_θ^1 a lattice of phases — the flavor alphabet, with spacing $\pi/5$ set by the ledger integer $L = 5$ — and the alphabet is *chiral*: read clockwise and counterclockwise it does not match. Figure 30 draws it. Four letters matter for everything downstream, and the campaign’s audit of the birth of matter (Arisaka, 2026, P5-CPT) graded each:

- $\delta_{\text{CKM}} = 2\pi/5$ — the quark sector’s phase: a *chiral bystander*. It makes the kaon and B -meson asymmetries of the laboratory, but its contribution to the cosmic excess is the famous $\sim 10^{-20}$ of the bound computed by Gavela et al. (1994) — real chirality, negligible throughput.
- $\delta_{\text{PMNS}} = \pi + 2\arcsin(1/7) = 196.4^\circ$ — the neutrino Dirac phase: a *spectator* to the excess (the washout-averaged asymmetry is blind to it at leading order), but the laboratory’s sharpest test of the lattice: DUNE and Hyper-Kamiokande measure it directly.
- $\alpha_{21} = 0$ — inert.
- $\alpha_{31} = \pi$ — *the driver*. The half-angle enters the decay amplitude as $e^{i\pi/2} = i$: maximal interference from an angle that is itself CP -even — the amount saturates while the orientation survives. The excess of matter (Problem 11) rides on this letter.

The anatomy’s sentence for the fate of CP : *the connection is symmetric; the tape is not*. CP breaking is not a property of the dynamics but of the groove — the constitution’s integers, pressed into the circle as a chiral lattice — and that is why its parameters neither run nor drift: they are holonomy-class data, exact at every scale, measured as angles.

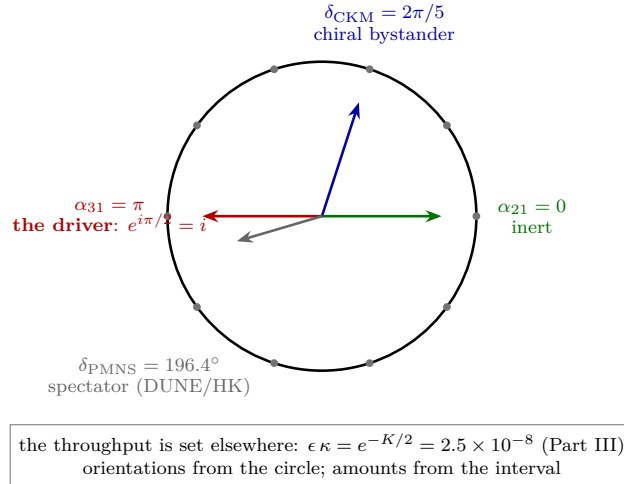


Figure 30: The chiral alphabet on the circle. The flavor phases sit on the $\pi/5$ lattice of S_θ^1 (dots). Four letters carry the discrete-symmetry story: the quark phase $\delta_{\text{CKM}} = 2\pi/5$ (chiral but negligible throughput), the neutrino Dirac phase $\delta_{\text{PMNS}} = \pi + 2\arcsin(1/7)$ (a spectator to the cosmic excess, the laboratory’s direct test of the lattice), the inert $\alpha_{21} = 0$, and the driver $\alpha_{31} = \pi$, whose half-angle $e^{i\pi/2} = i$ maximizes the interference that pays the matter excess. *The connection is symmetric; the tape is not* (Arisaka, 2026, P5-CPT).

33.4 Why T breaks at runtime

T reverses the clock, and the clock is fed by the fiber with no inverses. At the level of the *laws* — the bulk equations, the connection — reversing the clock is as innocent as reversing the circle. At the level of the *runtime* it is not, because the runtime is GDOS: the boundary’s open-system evolution, whose generator is the interval’s forward semigroup. A semigroup has no element that undoes another; a reversed clock would require exactly such an element; so T is broken wherever the runtime acts — in measurement, in decoherence, in every record — not because a T -violating term was added to a Lagrangian but because *the reading of the tape has a direction even when the tape does not*. This is the precise sense in which the arrow of time (Problem 13) and the fate of T are one fact. The microscopic T -violation of the weak sector (the CP violation above, read through CPT) is the circle’s contribution; the macroscopic irreversibility is the interval’s; and the two are independent in origin — which the anatomy displays and the textbook presentation obscures.

33.5 Where a preferred sense comes from at all

Before the calculus, one conceptual knot deserves untying, because it is where most readers first suspect circularity. A chiral alphabet presupposes that “clockwise” and “counterclockwise” differ — but the circle itself is unoriented, and the laws are even-handed. Where does the preferred sense come from? The campaign’s answer (Arisaka, 2026, W1-Symmetry; Arisaka, 2026, P5-CPT) is the determinism triad of Part II, applied to orientation itself: the constitution’s integers press a pattern into the circle whose two readings are *not* congruent (the pentagon’s chirality — content, not connection); the runtime reads the tape in the one direction the interval possesses; and the composite — chiral content, one-way reading — manufactures an *effective* orientation without either ingredient being an oriented circle or an asymmetric law. This is the resolution of the oldest form of the matter–antimatter puzzle (“symmetric laws cannot prefer”) in two moves: the laws do not prefer; the tape and the read-head jointly do. The reader will recognize the shape from Part II: it is Curie’s principle, dissolved — symmetric dynamics, asymmetric arithmetic — now applied to handedness itself.

33.6 The orientation calculus

Why exactly five operations, and why these? The real-bulk companion derives the discrete table from first principles (Arisaka, 2026, P4-Real), and the derivation is short enough to carry whole. The bulk supplies two global structures attached to every system — the phase circle (generator ∂_θ) and the constitutional clock (∂_t with the positivity clause of AX-3) — and the stage supplies its spatial orientation. Each structure admits exactly two senses; the discrete group of the geometry is therefore $\mathbb{Z}_2 \times \mathbb{Z}_2 \times \mathbb{Z}_2$: eight elements, generated by the three reversals, of which the identity is trivial and the seven non-trivial elements organize into the familiar five once the two mixed reversals that involve the clock alone are written as T -composites. Three consequences of the calculus are worth separating, because the textbook presentation runs them together:

- *Antiunitarity is not a postulate.* T reverses the clock, and the clock’s sense is what fixes the sign convention of frequency: positive energy means phases that rotate one way. Reversing the clock while preserving positivity forces complex conjugation — Wigner’s antiunitarity of T , here a corollary of orientation bookkeeping rather than an axiom of representation theory.
- *C is geometric, not internal.* Charge conjugation is the circle’s reversal, $\theta \mapsto -\theta$; it negates every winding at once, which is why no particle flips its electric charge without flipping its baryon and Q_i charges in lockstep — a correlation the internal-symmetry framing must impose representation by representation.
- *The composite CPT is inevitable.* With three orientations, the total reversal is the unique element that leaves no orientation for an invariant to lean on; its exactness (§33.2) is the statement that the geometry

has *only* these three orientations — no fourth hidden sense exists to be reversed. A *CPT* violation would be the discovery of a fourth orientation, which is why I treat the antihydrogen program as an arena test, not a model test.

33.7 The five fates, in one table

Table 12 is the census the argument has been building toward: five operations, and for each of them the structure whose orientation it reverses, whether the geometry admits that reversal, and the fate the laboratory reports. Read down the last column and the pattern is the whole of Problem 9 — three orientations the bundle can reverse and does, one it cannot, and one composite that inherits its fate from the others.

Table 12: The discrete symmetries by fiber: what each reverses, and why nature treats each as it does. Sources: (Arisaka, 2026, P5-CPT; Arisaka, 2026, P4-Real; Arisaka, 2026, A8-QM). Read down the third column and the pattern is the paper’s claim in five lines: *C* and *P* break because the alphabet on the circle is chiral and the interval’s agent couples chirally; *T* is exact in the books and broken at runtime, because the runtime rides the semigroup; *CP* breaks by angles that do not run; and *CPT* is exact, because reversing all three orientations is a relabeling under which no invariant moves.

Op.	Reverses	Fate	Why (the anatomy)
<i>C</i>	the circle’s sense	broken (with <i>P</i>)	the alphabet on the circle is chiral: content, not connection
<i>P</i>	the stage’s handedness	broken (weak sector)	the interval’s agent couples chirally (Problem 2): the descent selects a hand
<i>T</i>	the clock’s sense	exact in the books; broken at runtime	the runtime rides the semigroup: reading has a direction
<i>CP</i>	circle + stage	broken, by angles that do not run	the groove is chiral; its letters are holonomy classes
<i>CPT</i>	all orientations	exact	the total orientation is a relabeling: no invariant moves

One consequence deserves its own sentence here, because the next Problem is built on it: *C* broken in content but exact in the connection is precisely what an *antiparticle* needs in order to exist and to differ — the same class, the other reading. That is Problem 10, and §33.9 hands it over.

One number closes the audit, because it is the sharpest zero in the discrete-symmetry book: the driver angle. The flavor lattice’s Majorana phase is fixed at

$$\alpha_{31} = \pi \quad \Longrightarrow \quad e^{i\alpha_{31}/2} = i, \quad (37)$$

an exact lattice value, not a fit — the “driver” whose factor of *i* powers the gated crossing of Problems 10–11 — while the Dirac phase sits at the derived $\delta_{\text{PMNS}} = \pi + 2 \arcsin(1/7) = 196.4^\circ$ (a zero-parameter angle inside the experimentally favored quadrant). Both are checkable: DUNE and Hyper-Kamiokande measure δ_{PMNS} directly, and a value outside the derived-angle’s error budget kills the lattice reading at a named joint.

33.8 The alphabet, audited

The four letters of Figure 30 carry different jobs, different grades, and different laboratory handles; the audit deserves a table (Table 13), because the distinctions are exactly what a quick reading fuses.

Table 13: The four phases of the flavor alphabet, audited one at a time, because a quick reading fuses distinctions that carry different jobs, different grades and different laboratory handles. $\delta_{\text{CKM}} = 2\pi/5$ is a bystander, worth about 10^{-20} of the excess and tested in kaon and B -meson CP violation. $\delta_{\text{PMNS}} = \pi + 2\arcsin(1/7)$ is a spectator, blind at leading order, and DUNE and Hyper-Kamiokande are its handle. $\alpha_{21} = 0$ is inert. $\alpha_{31} = \pi$ is the driver, because $e^{i\pi/2} = i$. The last column names what would kill each: phases off the lattice, a PMNS phase away from 196.4° , a nonzero α_{21} effect, and Dirac rather than Majorana neutrinos.

Letter	Value	Role in the excess	Laboratory handle	Kill
δ_{CKM}	$2\pi/5$	bystander ($\sim 10^{-20}$)	kaon, B -meson CP	phases off lattice
δ_{PMNS}	$\pi + 2\arcsin(1/7)$	spectator (blind at LO)	DUNE / Hyper-K	$\neq 196.4^\circ$
α_{21}	0	inert	$0\nu\beta\beta$ combination	nonzero effect
α_{31}	π	driver ($e^{i\pi/2} = i$)	$0\nu\beta\beta$; cosmology	Dirac neutrinos

Two entries repay a second look. The quark phase is the largest *laboratory* CP effect and a negligible *cosmic* one — the bystander paradox — because throughput, not chirality, is what the excess rations (§34.6); the laboratory sees the letter, the cosmos sees the toll. And the driver $\alpha_{31} = \pi$ is a *Majorana* phase: it exists only if the light neutrinos are their own mirror reading. An established Dirac nature — no neutrinoless double-beta decay at any sensitivity reaching the allowed band — would delete the driver and retire the chain of Problem 11 in its present form: the anatomy would survive, its quantitative crown would not. The cohort stakes this plainly and counts the $0\nu\beta\beta$ program among its jurors.

33.9 The laboratory face of this Part

Three experimental programs read this Part directly. *Antihydrogen spectroscopy* (ALPHA and successors) compares the 1S–2S line across the C reversal: any splitting, at any precision, is a fourth orientation and kills the arena (§33.6). *Long-baseline neutrino oscillation* (DUNE, Hyper-Kamiokande) measures δ_{PMNS} : the lattice value $\pi + 2\arcsin(1/7) = 196.4^\circ$ is a zero-parameter target sitting in the experimentally favored quadrant, and a measured phase drifting off the lattice completion retires the alphabet as geometry (while leaving the anatomy’s qualitative reading of CP intact — the distinction matters and is stated here deliberately). *Electric dipole moments* probe the T -odd content of the books: the anatomy predicts the pattern — T violation in the laboratory only through the chiral alphabet’s letters, never as a new continuous source — so an EDM signal demanding a rogue phase off the lattice would wound the same joint. In all three cases the exposure is the campaign’s preferred kind: angles, not amplitudes — quantities the circle protects and the experiment reads whole.

Three mirrors broke and one held. The next Problem asks what the breaking was *for*: an antiparticle is the class held exactly, and the excess of matter over antimatter is the toll charged when the interval crossed the alphabet once.

34 Problem 10–11. The Origin of Antiparticles, and the Tiny Excess of Matter

34.1 What an antiparticle is

On the anatomy, a particle species is circle-side data: a holonomy class — charge as winding, spin, representation — wearing an interval-side mass ([Arisaka, 2026, P3-Electron](#)). An antiparticle is then not a second object but a second *reading*: the same circle-side class, traversed in the opposite sense of S_θ^1 — the mirror orientation. The consequences that the textbook lists as separate facts become one sentence each:

- *Exact mass equality.* The mass is the interval’s address of the class’s ground basin, and an address is orientation-blind: reading the tape backward does not move the groove. The positron matches the electron to the last measured digit because both are one basin, read twice ([Arisaka, 2026, P3-Electron](#); [Arisaka, 2026, P5-CPT](#)).
- *Exact charge negation.* Every charge is a winding, and reversing the circle’s sense negates every winding at once — which is why *all* charges flip together, not independently.
- *Existence.* The two readings exist because the circle has two senses; a world without antiparticles would need an oriented circle, and an orientation of S_θ^1 is exactly what no clause of the constitution supplies. The handshake between the circle’s two senses and the clock’s positivity requirement — the real-bulk companion’s antiparticle theorem — is what forces the pairing into every charged sector ([Arisaka, 2026, P4-Real](#)).

The deep question is therefore not why antimatter exists — the circle answers that — but why it *lost*: why the universe retains one part in 10^9 of unmatched matter. The anatomy’s answer occupies the rest of this Part, and it has the same shape as everything else in this paper: *the orientations come from the circle; the amounts come from the interval*.

The mirror’s origin, in the equation where it first appeared. A relativistic electron obeys the Dirac equation,

$$(i\gamma^\mu \partial_\mu - m)\psi = 0, \quad (38)$$

where ψ is a four-component field, m the mass, and the γ^μ four fixed matrices encoding how spin rides the Lorentz group. The equation’s solution space contains, for every positive-energy mode of charge q , a partner mode that behaves as charge $-q$ with the *same* m — antimatter was in the mathematics before it was in a cloud chamber. What the equation does not say is *why* the partner must exist. The anatomy’s answer: ψ ’s phase lives on the compact circle, and a circle has exactly two winding senses; the antiparticle is the same holonomy class read in the opposite orientation (Eq. (36)’s C), which is why the masses match to the last digit (a class has one magnitude, two senses) and why every charge — electric, baryon, lepton — negates jointly (all are windings). The mirror is exact because it is topological; nothing dynamical could have made it this clean.

34.2 Sakharov’s three conditions, as anatomy

Sakharov’s conditions ([Sakharov, 1967](#)) — baryon-number violation, C/CP violation, and departure from equilibrium — are, in the standard telling, three independent ingredients a model must somehow assemble. On the anatomy they are not ingredients but organs, one per structure ([Arisaka, 2026, P5-CPT](#); [Arisaka, 2026, W1-Symmetry](#)):

1. **B violation is the circle's topology meeting the weak sectors.** The $\Delta B = 3n$ sphaleron door — baryon number changing in steps of three — with $B - L$ exactly conserved (a circle-side ledger that never opens), and the door itself *welded cold*: at today's temperatures the crossing rate carries e^{-372} , the deepest suppression in the cohort. The books can change only through a named, quantized door, and the door is now shut.
2. **CP violation is the chiral alphabet** of Problem 9: the driver $\alpha_{31} = \pi$, whose half-angle supplies the i that maximal interference needs, with the pentagon's non-closure supplying the existence of a preferred sense.
3. **Nonequilibrium is the gated interval.** The descent crosses the lock threshold *once*, promptly, with zero dilution — the same once-only logic that releases the Kaxion (Problem 7) and ends inflation. Equilibrium is what a system reaches when it can revisit; the interval cannot revisit; the crossing is therefore out of equilibrium by topology, not by tuning.

Sakharov, read on the anatomy, is not a checklist but an anatomy lesson: *nonequilibrium is the gated interval, CP is the chiral circle, and the lawful ΔB channel is the circle's topology meeting the weak sectors* — one condition per fiber structure, none optional, none added by hand.

34.3 Why the neutrino sector is the pivot

That the excess should be paid through *neutrinos* — rather than through the quark sector that displays CP violation daily — is, on the anatomy, close to forced, and the reasons compound. *First, the door*: sphalerons process $B + L$ while conserving $B - L$; an asymmetry survives reprocessing only if written in $B - L$, and the one sector that writes lepton number without baryon number at high scale is the heavy-neutrino sector. *Second, the address*: the chain needs a once-only, out-of-equilibrium release, and the descent supplies exactly one gate at the right depth — the lock crossing at $M_{\text{lock}} = 3.85$ TeV, where the heavy state's decay races the expansion (the washout bookkeeping, with its regulator, is the parent paper's; the gate itself is the interval's). *Third, the letter*: the driver lives among the Majorana phases, and Majorana structure is native to the neutral sector alone — the charged fermions cannot carry it. So the pivot is not a model preference but an intersection: *the only sector that can write the surviving book, standing at the only gate the descent opens, holding the only letter that drives*. The quantitative chain of §34.5 is what that intersection pays.

34.4 The welded door, quantified

The door through which baryon number moves deserves its own numbers, because its two regimes are the anatomy in miniature (Arisaka, 2026, P5-CPT; Arisaka, 2026, A9-SM). Above the electroweak crossover, sphaleron transitions are unsuppressed: the door stands open, and the lepton asymmetry written at the lock crossing is reprocessed into baryons at the equilibrium conversion 28/79 — the door is a *channel* while the descent is hot. Below the crossover the sphaleron rate acquires the Boltzmann factor of the sphaleron energy, and the exponent today is not merely large but absurd: $\sim e^{-372}$, the deepest suppression in the cohort's books — zero crossings expected in the lifetime of the universe, multiplied by any conceivable volume. The door did not close; it *welded*. Two features matter for the anatomy. First, the weld is an interval event: it happened at an address (the crossover temperature), once, on the way down — the door's history is a descent history. Second, what the weld protects is a circle ledger: $B - L$ never opened at all (exact at every temperature), and $B + L$'s violation was quantized in units of three ($\Delta B = 3n$ — one unit per family, never one alone) even while the door stood open. The asymmetry of Problem 11 is thus doubly safe: written once through a quantized door, and the door then welded behind it. *The interval opened the door, the circle counted what passed, and the interval sealed it* — the three clauses of Sakharov, told as a history.

Figure 31 draws the landscape the chain crosses.

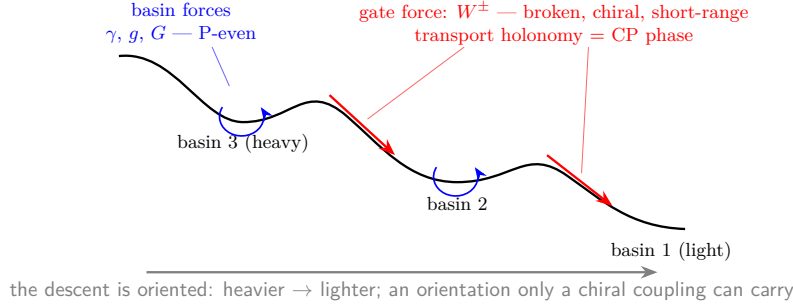


Figure 31: The family landscape and the gate (reproduced from [Arisaka, 2026, P5-CPT](#)). The flavor lattice’s basins with the one gated crossing marked: unbroken forces hold their charges fixed (the deep basins — the circle’s protected classes), and the matter excess is written at the single one-way passage whose toll is the $e^{-K/2}$ of Eq. (40). The geometry makes Sakharov’s third condition structural: the crossing is out-of-equilibrium because the descent never repeats an address, and the door it passes through is welded behind it (Problem 12).

34.5 The chain, quantitatively

The CPT companion’s Part VIII assembles the excess end to end ([Arisaka, 2026, P5-CPT](#)); Figure 32 draws the chain, and this section carries its numbers at the declared grade. The heavy neutrino released at the lock crossing decays with an asymmetry whose *orientation* the alphabet fixes and whose *throughput* the descent prices:

$$\epsilon \kappa = e^{-K/2} = e^{-17.5} = 2.5 \times 10^{-8}, \quad (39)$$

the efficiency-times-asymmetry product carrying the topological toll of half the lock depth (the $K/2$ exponent is the chain’s one *postulated* step, named as such). Sphaleron conversion reprocesses the lepton asymmetry with the standard factor $28/79$, dilution by the entropy bath divides by g_* , and the triplet’s equilibrium yield $\sum_i Y_{N_i}^{\text{eq}} \simeq 1.25/g_*$ ($0.42/g_*$ per species) is displayed rather than absorbed. The assembled prediction,

$$\eta_B = 7.04 \cdot \frac{28}{79} \cdot \frac{1.25 e^{-K/2}}{g_*} = 7.34 \times 10^{-10} \quad \text{vs.} \quad \eta_B^{\text{obs}} = 6.12 \times 10^{-10}, \quad (40)$$

a +20% agreement (headline $\eta_B \approx 7 \times 10^{-10}$, band $\times 3^{\pm 1}$) carried at grade D*: one named input (the geometric phase assignment C-P5-C/H- $\varphi_{\text{geo}}-1$), one named regulator (the flavor-measurement width $\Delta M/\Gamma^{\text{eff}} = 1/(35 c_\tau y_\tau^2)$), and the $K/2$ exponent postulated — stated here exactly as the parent paper states them, because the honesty *is* the result: a number this close, from a chain this constrained, is meaningful only if its open joints are named. (The parent’s Boltzmann integration now *measures* the kernels’ one-sided window deficit: $E = 7.1$, 68% [4.4, 11.4].)

34.6 Why one part in a billion

The most striking feature of the excess is its size: not 10^{-3} , not 10^{-15} , but 6×10^{-10} . On the anatomy the magnitude is a *topological toll*, and its size is readable before the detailed chain is run. The throughput (39) is $e^{-K/2}$: half the lock depth, the one hierarchy the interval ever wrote, spent once. With $K = 35$,

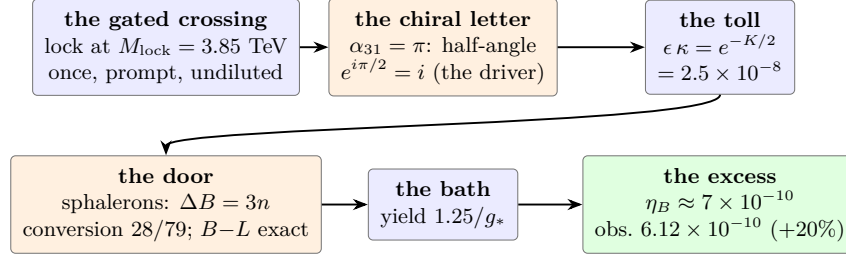


Figure 32: The birth of the excess, as anatomy. Blue boxes are the interval’s (the once-only crossing, the exponential toll, the bath); orange are the circle’s (the chiral letter, the quantized door with its exact $B-L$ ledger); the output is the measured baryon-to-photon ratio, reproduced at +20% at grade D* with the parent paper’s named input, named regulator, and postulated $K/2$ exponent stated in place (Arisaka, 2026, P5-CPT).

$e^{-17.5} = 2.5 \times 10^{-8}$; the sphaleron conversion and the entropy bath then supply the order-one and order- 10^{-2} dressing that lands the final answer at $\approx 7 \times 10^{-10}$. The contrast with the two standard families of mechanism is instructive and honest. Electroweak baryogenesis draws its smallness from a product of small dynamical factors (a weak phase, a thin bubble wall, a mild transition) — each adjustable, which is why the literature spans decades of predicted magnitudes. GUT-scale baryogenesis draws it from washout races — again adjustable. Here the magnitude is one exponential of one ledger integer, with the exponent’s factor of $\frac{1}{2}$ the chain’s named postulate: if the toll is right, it is right for a reason a critic can check against a single integer; if it is wrong, there is no dial to save it. The excess is one part in a billion because half a lock depth *is* $10^{-7.6}$, and the universe paid the toll exactly once.

34.7 The three horizons of sameness

The excess is one instance of a wider fact this Part should name before closing: the universe is *the same* in three progressively stronger senses, and the anatomy prices each (Arisaka, 2026, A10-Cosmos; Arisaka, 2026, W1-Symmetry). *Horizon 1: the same conditions* — temperature, curvature, and inventory uniform across causally disconnected patches: bought by the interval’s opening act (inflation stretches one patch over the sky). *Horizon 2: the same things* — every region built of the same electrons, the same protons, the same abundances: bought by the circle’s ledgers (identity is a holonomy class, and classes are the same everywhere without communication — no mechanism need synchronize what topology makes identical). *Horizon 3: the same choices* — every region on the same side of every symmetry breaking: matter over antimatter, this vacuum, this alphabet: bought by the determinism triad — the dial, the floor at its stated condition, and the once-only reading (§18) — with the excess of this Part its sharpest instance. A tuned universe would have to tune each region; a lottery universe would have to correlate its draws; the read tape does neither, because a groove plays back the same in every player. The three horizons are the anatomy’s answer to the oldest observational fact about the universe — its monotonous, extravagant sameness — and the excess is horizon three, audited against a number two independent methods measure to the per-cent level.

34.8 Why a universe of matter was inevitable

Assemble the Part. The circle guarantees that matter and antimatter exist as two readings of one book, degenerate in every address. The chiral alphabet guarantees a preferred sense — pressed into the tape by the constitution’s integers, not chosen by history. The interval guarantees a once-only, out-of-equilibrium crossing at which the preference could act, and prices its throughput with a topological exponential. And the

quantized door guarantees the asymmetry, once written into baryons, is kept: $B - L$ never opens, and the sphaleron door welds shut at e^{-372} as the descent cools. Nothing in the sequence is contingent: given the constitution, a universe that ends the crossing with exactly the observed one-in- 10^9 residue of unmatched matter is not one lucky outcome among many but the deterministic playback of the groove — *the excess of particles is the one-way reading of a chiral tape*. The reader who wants the fate of that residue — how it welds into protons that never decay — goes to Problem 12; the reader who wants the clock it set ticking goes to Problem 13.

34.9 Seminar questions

Where did all the antimatter go, physically? It annihilated — essentially all of it, against essentially all of the matter, in the first seconds; the photon bath of the microwave background is, in large part, that bonfire’s light. What survived is the unmatched residue: one part in a billion, the excess this Part computes. The universe of galaxies is not matter’s triumph over antimatter; it is the change left over from their mutual settlement.

Could the antimatter instead be segregated — antimatter galaxies somewhere else?

Observation says no (Problem 8’s audit: no annihilation seam in the gamma-ray sky at any scale), and the anatomy says why it could not be otherwise: the excess’s sign is set by the chiral alphabet — circle-side content, identical in every region — so every patch tips the same way. Segregation would require Horizon 3 to fail exactly where the groove holds it strongest.

Does antimatter fall differently? No — and the anatomy is committed: an antiparticle is the same class read in the mirror, and the mass is the class’s address, orientation-blind. The antihydrogen free-fall measurements are therefore an audit of the mirror reading itself; any anomalous gravitational behavior of antimatter would break Problem 10 at its root, well before it troubled general relativity.

Why should the excess involve neutrinos rather than the quarks that show CP violation daily? Because the door, the address, and the letter intersect only there (the pivot section above): sphalerons preserve $B-L$, so only an asymmetry written in lepton number at high scale survives reprocessing; the descent’s one gate sits at the lock; and the driver is a Majorana phase, which charged fermions cannot carry. The laboratory’s flashiest CP violation and the cosmos’s effective CP violation live in different sectors for structural, not accidental, reasons.

34.10 The decade of the excess

Problems 10–11 are unusually well served by instruments, and the audits partition cleanly by letter. *The bystander* ($\delta_{\text{CKM}} = 2\pi/5$): LHCb and Belle II continue to tighten the quark unitarity triangle — every improvement audits the lattice’s quark letter, though none touches the cosmic books. *The spectator* ($\delta_{\text{PMNS}} = 196.4^\circ$): DUNE and Hyper-Kamiokande will measure the neutrino Dirac phase directly — the lattice’s cleanest zero-parameter target, in the experimentally favored quadrant. *The driver* ($\alpha_{31} = \pi$): neutrinoless double-beta decay is the arbiter of its Majorana prerequisite — next-generation tonne-scale experiments reach the band where the framework’s neutrino sector lives, and an established Dirac nature retires the chain in its present form. *The door*: collider electroweak studies continue to check the sphaleron-era bookkeeping’s premises. And *the output* itself — η_B — is measured two independent ways (CMB acoustics and primordial abundances) whose concordance is re-audited with every data release. The excess is not a

story about the early universe only; it is a live accounting across five experimental programs, and the chain of §34.5 owes each of them a number.

The excess survived because a ledger the interval could not undo had already been written. The last Problem of this Part asks what else that ledger protects — and finds the quark that cannot be seen and the proton that cannot decay held by the same two books.

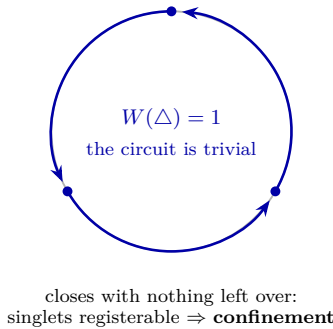
35 Problem 12. Quark Confinement, and the Absolutely Stable Proton

35.1 The triangle and the pentagon

Problem 9 found the flavor sector pressing a *pentagon* of phases into the circle — steps of $2\pi/5$, set by $L = 5$ — whose circuit carries a chiral holonomy: the loop closes as a path, but the reading accumulates a phase, and that surviving phase is CP violation. The color sector presses the complementary figure: a *triangle* — steps of $2\pi/3$, set by $N = 3$, the triality of $SU(3)_C$ — and the triangle differs from the pentagon in the one respect that decides everything: *its circuit is trivial*. Three color steps compose to the identity; the loop closes with nothing left over; the holonomy is 1. Figure 33 draws the pair.

The physics of confinement is then one sentence (Arisaka, 2026, P6-Proton; Arisaka, 2026, W1-Symmetry): *only configurations whose total color circuit is trivial can be handed to the boundary*. OGGEF registration marginalizes the fiber; a state whose color holonomy is nontrivial is a state whose description cannot be closed without the fiber coordinate the projection erases; such a state cannot be an observable of the boundary at all. A single quark — one step of the triangle, holonomy $e^{2\pi i/3}$ — is therefore not merely bound by a strong force; it is *unregisterable*: not a thing the boundary can hold. The observable states are exactly the closures — three steps (qqq : the baryon) or a step and its inverse ($q\bar{q}$: the meson) — which is the color-singlet rule of the textbook, derived from registration rather than assumed from dynamics. Confinement, on the anatomy, is not a statement about the growth of a potential but about the topology of the bookkeeping: *the circle will not hand the boundary an open book*.

(a) The color triangle ($N = 3$)



(b) The flavor pentagon ($L = 5$)

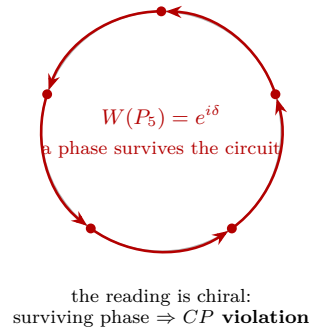


Figure 33: Two figures on one circle, two fates. (a) The color triangle: three steps of $2\pi/3$ compose to the identity; a closed circuit with trivial holonomy is a book the boundary can register — singlets exist, single quarks do not, and confinement is the registration rule. (b) The flavor pentagon: five steps of $2\pi/5$ whose chiral reading leaves a surviving phase — the CP violation of Problem 9. Same circle, same anatomy: *closure without residue confines; closure with residue violates* (Arisaka, 2026, P6-Proton; Arisaka, 2026, P5-CPT).

Two established equations frame what any account of confinement must reproduce. The static potential between a heavy quark and antiquark, measured on the lattice and in quarkonium spectra, is Cornell-form:

$$V(r_{q\bar{q}}) = -\frac{4}{3} \frac{\alpha_s}{r_{q\bar{q}}} + \sigma r_{q\bar{q}}, \quad \sqrt{\sigma} \approx 440 \text{ MeV}, \quad (41)$$

Coulombic at short distance (the $-4\alpha_s/3r$ of one-gluon exchange) and *linear* at long distance — the potential of a string of constant tension σ , so that separating a pair costs energy without bound and the vacuum answers by creating a new pair instead. Equivalently, in Wilson’s own diagnostic (Wilson, 1974), a large loop of perimeter-enclosing area $\mathcal{A}$ obeys the area law

$$\langle W(C) \rangle \sim e^{-\sigma \mathcal{A}(C)}, \quad (42)$$

exponential suppression by the *area*, not the perimeter — the loop-language signature that isolated color cannot be transported. The anatomy adds the why beneath the what: color holonomy on the compact fiber closes only in threes (the $\mathbb{Z}_3$ center), so an open color line is not an expensive state but an *unregistrable* one, and Eq. (41)’s string is the boundary’s price for attempting it. The proton’s side of the Part is a number: $\tau_p > 2.4 \times 10^{34}$ yr (Takenaka et al., 2020), twenty-four orders beyond the age of the universe, guarded by the two independent closures of §35.5 — one on what can move, one on what can be written.

35.2 The abelian ledger and the singlet rule

The triangle has an abelian shadow, and the shadow is where the proton’s guard is written. The baryonic circle $U(1)_B$ counts, per revolution of S_θ^1 , one unit of baryon number; the color triality t and the electric charge Q ride the same fiber-bookkeeping; and the fragment-level audit of (Arisaka, 2026, P6-Proton) verifies, state by state through the entire zoo, two integrality guards:

$$Q + \frac{t}{3} \in \mathbb{Z} \quad \text{and} \quad Q + B \in \mathbb{Z}, \quad (43)$$

with the $\mathbb{Z}_6$ quotient of the joint lattice verified trivial fragment by fragment. Equation (43) is the singlet rule in ledger form: the circle’s several windings are not independent books but one cross-ruled ledger, and only entries that balance across the rulings are registerable. It is worth being precise about what kind of rule this is, because the next section leans on it. Eq. (43) is a *registration* rule on states — it says which entries the ledger admits — not a selection rule on transitions. What it delivers to the proton is prior to any decay argument: it is the reason B and the charge–triality combination are *integers* at all, so that they can be holonomy classes rather than continuously varying quantities. A fractional charge, a free triality, an unpaired baryon unit — each would be an entry that fails a ruling, and the anatomy disposes of them all at once: they are not forbidden by a force; they are *unwritable*.

Figure 34 shows the measured potential — the cage, quantified.

35.3 Why three colors

The triangle’s power derives from its corner count, so the count itself should be traced. $N = 3$ is a ledger member, and the cohort reaches it by a chain in which no color count is assumed: $M = 1$ by dimensional minimality; $L = 5$ by single-tensor Green–Schwarz consistency; and N from the constitutional relation $J = 2N + 1$ substituted into the dual lock, giving $N = L \pm \sqrt{L - M^2}$ with roots $\{3, 7\}$ at $L = 5$ and minimality selecting 3 (Arisaka, 2026, W1-Symmetry; Arisaka, 2026, A2-GG6). Independently, the family count $N_g = 3$ is reached by the capacity pincer of (Arisaka, 2026, P2-N3) — *two derivations sharing no premise, arriving at the same small integer* from opposite sides, which the cohort regards as stronger evidence

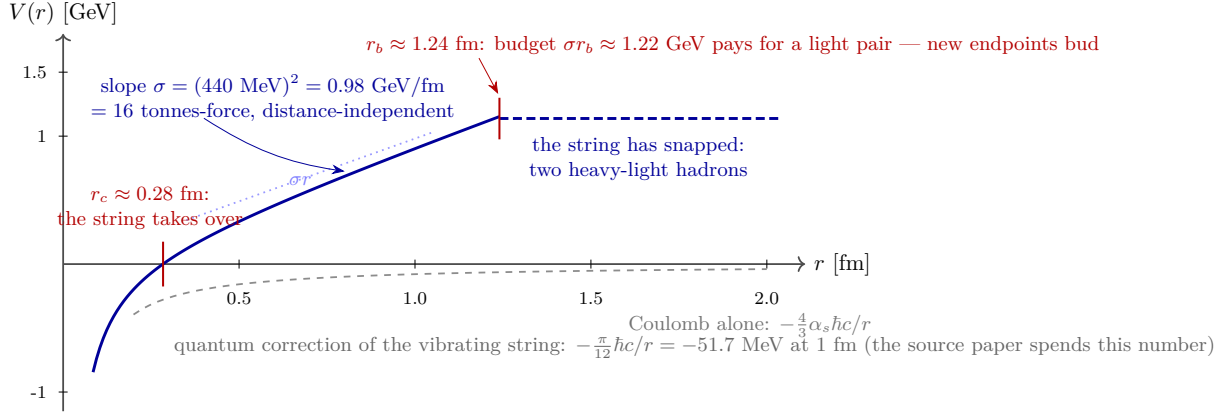


Figure 34: The measured cage (reproduced from [Arisaka, 2026, P6-Proton](#)). The static quark–antiquark potential of Eq. (41) across its two regimes: Coulombic below ~ 0.3 fm, linear above, with the string tension σ as the slope and the lattice/quarkonium data fixing both pieces. The crossover distance is where the running coupling of Eq. (20) leaves the perturbative regime — the interval’s reading failing at exactly the address where the circle’s closure rule takes over the description.

than either alone. The anatomy’s addendum is the division of labor this Part has used throughout: the *count* is circle-side (an integer in the ledger, unable to run — the triangle has had three corners since before the first second), while everything *dynamical* about color — the running of α_s , the confinement scale, the hadron masses — is interval-side dressing on a fixed topological skeleton. Three colors is not a fact about forces; it is a fact about the tape.

35.4 The zoo, audited

A guard is only as good as its audit, and the audit exists: the proton companion verifies the two rulings of (43) *fragment by fragment* across the hadron zoo ([Arisaka, 2026, P6-Proton](#)) — every baryon, every meson, every exotic candidate the tables list — confirming in each case that $Q + t/3$ and $Q + B$ land on integers and that the joint $\mathbb{Z}_6$ quotient of the charge–triality–baryon lattice is trivial: no state, anywhere in the observed spectrum, occupies a cell the ledger forbids, and no forbidden cell is approached even by the exotica. Three structural remarks ride on the audit. *First*, the audit is a census, not a sample: integrality is the kind of claim a single counterexample kills, so the companion checked all of it, programmatically, and this paper repeats the claim only because the check exists. *Second*, the mesons matter as much as the baryons: a $q\bar{q}$ state closes by inverse rather than by triple, and the ledger’s arithmetic must — and does — treat the two closures consistently, which is a nontrivial cross-ruling of the same books. *Third*, the audit is where the anatomy’s darkness argument gets its hadronic face: the zoo contains no fractionally charged survivor because a fractional charge is an open book, and Part II’s registration rule does not hand open books to the boundary. The empirical support for confinement-as-bookkeeping is thus not one experiment but the entire hadronic table, read as a ledger and found balanced.

Figure 35 prices the proton’s mass — mostly confinement, hardly Higgs.

35.5 The stable proton: the double guard

Why does the proton not decay? The standard model answers “accidental symmetry”; grand unification answers “it does, at 10^{34} years”; experiment so far answers “not yet, anywhere.” The anatomy’s answer ([Arisaka, 2026, P6-Proton](#)) has two clauses, and it is worth separating them, because they do different work.

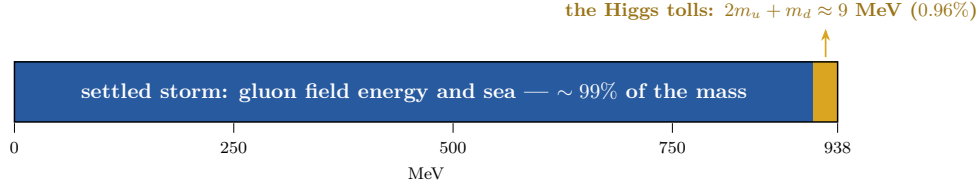


Figure 35: The proton’s mass budget (reproduced from [Arisaka, 2026, P6-Proton](#)). Where the 938 MeV actually resides: the three valence quarks’ Higgs-coupled masses contribute of order one percent; the remainder is confinement’s own energy — the gluon field and quark kinetic terms of the closed color books. The pie is the sharpest one-picture rebuttal of “mass comes from the Higgs”: what the Higgs gives the proton is the pencil-weight of its quarks; what the circle’s closure rule gives it is the body. Mass as “the address a class wears” (Problem 14) is this budget, generalized.

The first clause is conservation. Baryon number is not an approximate bookkeeping device here; it is a holonomy class on $U(1)_B$, an integer on the fiber that remembers, and holonomy classes do not leak. The only door through which B moves at all is the $\Delta B = 3n$ sphaleron channel of Problem 11 — quantized, B – L -preserving, and welded cold at e^{-372} . A $\Delta B = 1$ transition is not suppressed by a large mass; there is no aperture of that size in the geometry.

The second clause is registration. Suppose one insisted on writing a $\Delta B = 1$ operator anyway. Its intermediate carries an unbalanced color triality, and by Eq. (43) such a state is not expensive but *unregistrable* — it is not an entry the cross-ruled ledger admits.

Here the honest register requires more care than the phrase “double guard” invites, and the paper would rather draw the line itself. Eq. (43) alone does not forbid the decay: integrality is satisfied on both sides of $p \rightarrow e^+ \pi^0 \rightarrow Q + B$ moves from 2 to 1, and both are integers, and the reader should check it — so a statement of the guard leaning on integrality alone would be wrong. Nor is registration a second, independent closure. It is a rule on *states*, not a selection rule on transitions, and a virtual intermediate is not a registered state. The two clauses are therefore not two doors but a door and its hinge: the load is carried by the gauged $U(1)_B$, which forbids $\Delta B \neq 0$ at every operator dimension, and registration is what makes B an integer class rather than a continuous bookkeeping label — prior to the conservation law rather than parallel to it. That is the double guard properly stated, and it is why the proton’s stability is not a coincidence of small couplings but a property of the arena. The audit fragment by fragment is [Arisaka \(2026, P6-Proton\)](#)’s. The proton’s stability is thus the same fact as the electron’s identity, one Part earlier: permanence deposited on the circle. The residue of Problem 11’s excess — the one-in- 10^9 of unmatched matter — is stored in a vessel the anatomy itself guarantees: *the excess was written by the interval, once; it is kept by the circle, forever*. Exposure, stated plainly: the guard is falsifiable on two fronts. An observed proton decay in any channel violating the double guard — at Hyper-Kamiokande’s reach or anywhere — kills the ledger reading outright; and an observed fractionally-charged or free-triality state kills the quotient’s triviality. The cohort stakes both.

35.6 What the guard buys: from the zoo to the biosphere

The double guard’s payoff does not stop at particle physics, and one paragraph of reach belongs here. A proton stable beyond 10^{34} years is the precondition for *chemistry having a history*: nuclei that persist, a periodic table whose entries do not expire, molecular records — DNA among them — whose integrity over 10^9 -year evolutionary times rests on baryon number never leaking even once in 10^{40} opportunities per gram. The anatomy’s identity results compound the point: every proton is the same proton (the class argument of [Arisaka, 2026, P3-Electron](#), run on the welded baryon), so chemistry is not merely stable but *universal*.

— the same periodic table in every galaxy, the same binding energies, the same biochemical options, with no mechanism required to enforce the uniformity (Horizon 2 of Problem 11). When the cohort’s capstone traces the origin of structure from the GUT edge to the biosphere (Arisaka, 2026, A11-Origin), the two clauses it leans on at every rung below nucleosynthesis are this Part’s: *the books do not leak, and the books are everywhere the same*. The reader inclined to regard confinement and proton stability as parochial strong-interaction facts should reprice them here: they are the underwriting of every promise chemistry and biology have ever kept.

35.7 Strong CP, dissolved in passing

One classic puzzle of the color sector belongs to this Part’s close because the anatomy retires it almost without effort. The strong-CP problem asks why the QCD vacuum angle $\bar{\theta} \lesssim 10^{-10}$ when nothing in the standard model protects it. On the anatomy, $\bar{\theta}$ is a circle-side angle whose value is not an input but an occupation: the compact-angle sector relaxes, by the GRIP cascade, to a ground attractor of its stratum, and that floor is the CP -conserving point — with the fence §18 attaches to this stratum, which is one-dimensional and periodic and on which no uniqueness of the floor is claimed, so that the selection of the CP -conserving point is a statement about the floor reached and not about the absence of others — the same selection, run on the same landscape, that stabilizes the Kaxion (Problem 7). The alignment is not a new mechanism bolted on (a Peccei–Quinn sector introduced for the purpose); it is the geometric realization of that mechanism by a field the constitution already forced to exist (Arisaka, 2026, C1-Kaxion; Arisaka, 2026, A9-SM). The laboratory-facing residue is the 1.95 GHz line of Problem 7: the angle’s relaxation is still ringing, and the ring is detectable.

Figure 36 draws the result as a pair of dials: the strong sector’s angle free to relax to zero because nothing on the circle pins it, the weak sector’s locked at a lattice point because something does. One geometry, two fates, and the difference is which fiber holds the dial. The figure is the CPT companion’s, and its two Wilson-line readings are carried here at that companion’s grade: the anomaly and runtime papers now fix both Abelian circle holonomies as background data on the admissible class, with their fluctuations registered as exposures, and derive the Kaxion as the tensor remnant rather than as the $U(1)_{Q_i}$ Wilson line (Arisaka, 2026, A3-BI6; Arisaka, 2026, A6-GRIP); the locked dial is then a background datum and the relaxing dial a tensor mode, and the two-fate contrast survives that relabeling while its mechanism is the companions’ to restate.

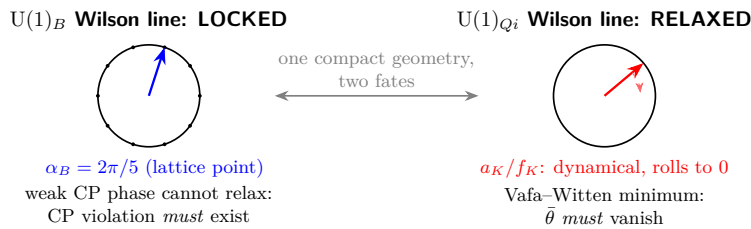


Figure 36: The two-fate architecture of the strong- CP answer (reproduced from Arisaka, 2026, P5-CPT). Two Wilson lines, two fates: the $U(1)_B$ line is *locked* — its holonomy a pentagonal lattice point, which is why the weak- CP phases are exact lattice angles — while the $U(1)_{Q_i}$ line is *relaxed* — free to slide, and slid to the energy-minimizing alignment that cancels the QCD vacuum angle. One geometry, one locked dial and one relaxing dial: the Peccei–Quinn mechanism realized by a field the constitution already owns (the Kaxion, Problem 7), with the neutron-EDM bound $|\bar{\theta}| \lesssim 10^{-10}$ (Abel et al., 2020) as the running audit.

Part V in one paragraph, and what comes next

Four problems of matter, one division of labor. The discrete symmetries are orientations a bundle may or may not admit: C , P and T reverse structures the geometry can reverse, and CPT is the total orientation it cannot — which is why three fail and their product does not. An antiparticle is the same holonomy class read the other way, so its existence and its exactness are one fact. The excess is a toll paid once on a chiral alphabet, computed to $\eta_B \approx 7 \times 10^{-10}$ (central 7.34) against a measured 6.12×10^{-10} , with the one postulated exponent named in place rather than buried. Confinement is the circle's registration rule — color books balance only in triples — and the proton lives because baryon number is a gauged class with no $\Delta B = 1$ aperture.

Four problems of matter are behind us; the last four ask what the arena is made of. Part VI takes time, the three quantities we use most and define least, whether the constants were selected rather than explained, and the horizon that has been the discipline's sharpest instrument for fifty years.

Part VI

Foundation of the Cosmos

Problems 13–16: Time, the Three Currencies, the Landscape, and the Black Hole

The four problems of this Part are the ones physics shares with philosophy — what time, energy, and existence are, and whether our universe is one of many. All four are developed below; Problem 13 carries the fullest quantitative apparatus.

36 Problem 13. The Definition of Time, and the Arrow of Time

36.1 What time is, on the anatomy

“What is time?” has, in this geometry, a two-part answer, one part per fiber ([Arisaka, 2026, P5-CPT](#); [Arisaka, 2026, W1-Symmetry](#)):

The circle gives time its tick; the interval gives time its direction.

The *tick* is repetition, and repetition is the circle’s gift: a clock is anything that returns — a phase that comes back to itself and can be counted. Every real clock in physics is, traced to its root, a circle-side return: the Compton clock of a massive particle ($\nu = mc^2/h$; for the electron, 1.24×10^{20} Hz), the hyperfine line of cesium that defines the second, the Kaxion’s 1.95 GHz ring (Problem 7), and, slowest, the inverse Hubble time. The available range, Planck frequency down to the Hubble rate, is the e^{140} of the age ledger; this ladder samples e^{87} of it, from the electron’s 1.24×10^{20} Hz to 2×10^{-18} Hz — and every rung is quantized counting on the fiber that remembers. Energy, by Noether, is what the symmetry of the tick is worth — which is why the first law is the circle’s ledger and can never be one-way (Table 4).

The *direction* is the interval’s: the runtime reads the tape once, forward, because its generator is a semigroup. No dynamical law supplies this arrow — the books are T -symmetric (Problem 9) — and none needs to: the arrow is the topology of the fiber the reading runs along. Entropy is the count of the one-way writes — what the arrow of time has *read* — which is why the second law is the interval’s ledger and can never repeat. The famous tension between exact mechanics and irreversible thermodynamics dissolves into a division of labor between a group and a semigroup ([Arisaka, 2026, A5-GDOS](#)).

36.2 The four endowments

The CPT companion’s expanded treatment organizes what a definition of time must supply as four endowments, each now located on the anatomy ([Arisaka, 2026, P5-CPT](#)):

1. **A tick** — something that repeats, so that duration can be counted. Supplied by the circle: every clock is a return (§36.1).
2. **An arrow** — a direction that distinguishes before from after. Supplied by the interval: the semigroup’s one-way composition (§36.1).
3. **A rate map** — a lawful relation between the tick and the arrow, so that histories can be dated rather than merely ordered. Supplied by the seam: $d \ln t / dr = 2$ in the radiation era, the exponential shadow of the linear descent (§36.3).

4. **A start and a reach** — an origin for the count and a horizon for its extent. Supplied by the descent’s endpoints: the launch at the top of the corridor, the de Sitter terminus at the bottom (Problem 7), with the whole reach audited by the age ledger (45).

Set against the standard menu — Newton’s absolute time (an endowment list postulated whole), relativity’s proper time (a rate map with no arrow), thermodynamics’ arrow (an arrow with no tick, borrowed statistically), quantum mechanics’ parameter time (a tick with no arrow) — the anatomy’s answer is not another entry but an assembly instruction: the four endowments come from two fibers and their seam, and no single structure could have supplied all four, which is why every one-structure definition of time has spent a century failing in a characteristic direction. Time is not a primitive and not an illusion; it is a *joint reading* — the circle’s count of the interval’s passage.

Figure 37 places the four endowments on the anatomy.

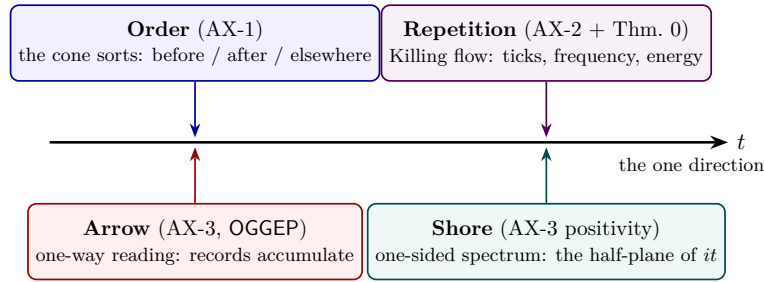


Figure 37: The four endowments of the direction called time (reproduced from [Arisaka, 2026, P5-CPT](#)). Each endowment located on its structure: the *tick* on the circle (a phase that returns, $E = h\nu$), the *arrow* on the interval (a transport that does not), the *rate* at the seam (the chronology’s exact slope, Eq. (44)), and the *extent* on the boundary (the age ledger, Eq. (45)). “Time” is the name physics gives the four jointly; the century of confusion came from asking one structure to supply all four.

36.3 The chronology is exact

The definition would remain philosophy if the geometry did not also *compute* the history. It does, and the computation is the sharpest quantitative result of the campaign ([Arisaka, 2026, P5-CPT](#); [Arisaka, 2026, A10-Cosmos](#)). In the radiation era the boundary clock and the radial coordinate obey

$$\frac{d \ln t}{dr} = 2 \quad \text{exactly,} \quad (44)$$

(verified numerically along the derived history to two percent away from the QCD transition, where the collapse of $g_*(T)$ dresses the slope — see §36.6), with the matter-era slope $3/2$; boundary time is the exponential shadow of the linear descent — one unit of r costs $e^2 \simeq 7.4$ in t . The whole history of time is one straight line with a single kink, and Figure 38 draws it: launch, lock, electroweak, QCD, BBN, matter–radiation equality, recombination, today — uniform in the geometry, exponential in the clock.

The endpoint is an audit that closes. The age of the universe, as an e-fold ledger on the descent,

$$\ln \frac{t_0}{t_{\text{Pl}}} = 140.24 = \underbrace{36.11}_{\text{launch}} + \underbrace{91.60}_{\text{radiation}} + \underbrace{12.53}_{\text{matter}+\Lambda}, \quad (45)$$

from standard kinematics and the cohort’s derived T_{rh} — nothing else. Two structural markers deserve their

own sentences. *First*, the corridor switch sits at $\ln z_{\text{sw}} = 7 = J$, i.e. $z_{\text{sw}} = e^7 = 1096.6$: a ledger integer planted in the middle of the chronology, exact and unrunnable — and distinct, by the cohort’s two-quantity discipline, from the *atomic* decoupling $z_{\text{dec}} \approx 1090$, which the atomic chain derives independently (0.11–0.16% raw); the falsifier F7 is the atomic quantity, observable-only. *Second*, the compression $140.24 = 4K \times 1.0017$ is carried at flagged grade and no higher: its would-be derivation is the e-fold budget campaign, and until that lands it is a coincidence worth exactly one flag. The ratio β/t — the thermal period against the age — falls monotonically down the same descent: the precise sense in which the universe becomes ever more classical (Arisaka, 2026, P5-CPT; Arisaka, 2026, A5-GDOS).

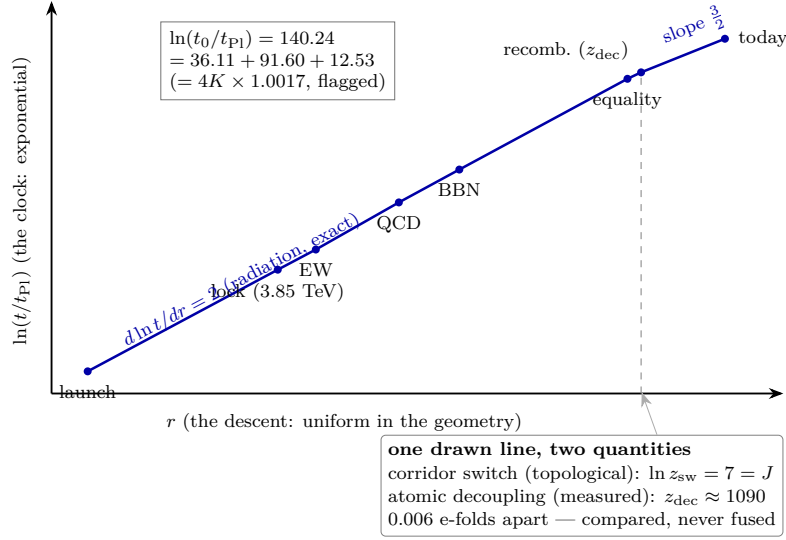


Figure 38: The whole history of time, on one line. The chronology of the descent in the $(r, \ln t)$ plane: uniform in the geometry, exponential in the clock, with the single kink at matter–radiation equality ($2 \rightarrow 3/2$). Epochs from the derived history of Arisaka (2026, A10-Cosmos); the age ledger closes at 140.24 (Arisaka, 2026, P5-CPT). The dashed line carries two distinct quantities that this axis cannot separate: the topological corridor switch at $\ln z_{\text{sw}} = J = 7$, and the atomic decoupling $z_{\text{dec}} \approx 1090$ that the atomic chain derives and recombination measures. They lie 0.006 e-folds apart — a gap smaller than the width of the drawn line, which is exactly why the cohort insists on naming which is which at every site, and why the falsifier F7 is written against the *atomic* quantity only. *Cosmic history is the one-way reading of holonomy data: the descent deposits on the boundary the letters stored on the fiber.*

One line of algebra makes the chronology concrete. In the radiation era the exact slope $d \ln t / dr = 2$ (Eq. (44)) integrates to the standard relation

$$H = \frac{1}{2t}, \quad T \propto e^{-r} \Rightarrow t \propto T^{-2} : \quad (46)$$

the Hubble rate H (the fractional expansion per unit boundary time) is the reciprocal of twice the age, and each e-fold of cooling costs exactly two e-folds of clock. The parameters: t is boundary proper time since the launch’s receipt, T the photon temperature, r the interval’s coordinate. The physical content — and the reason cosmology can do without a fundamental time variable — is that t is *derived* bookkeeping: the descent’s odometer converted at a fixed exchange rate, which is why the age ledger of Eq. (45) can close to four digits with no clock anywhere in the axioms.

36.4 The clock ladder

The tick’s circle-side character is not an abstraction; it is a ladder of laboratory returns spanning the full dynamic range of the universe, every rung a counted phase (Table 14).

Table 14: The clock ladder: four laboratory returns spanning thirty-eight orders of magnitude in rate, every rung a counted phase. The electron Compton frequency at 1.24×10^{20} Hz returns the mass’s own phase, the class’s own tick. The cesium hyperfine transition at 9.19×10^9 Hz returns an atomic phase and is what defines the second. The Kaxion line at 1.95×10^9 Hz returns the dark condensate, the GGA Hessian ringing. The Hubble rate near 2×10^{-18} Hz is the interval itself, read as a rate.

Clock	Rate	What returns	Fiber reading
electron Compton	1.24×10^{20} Hz	the mass’s phase	the class’s own tick
cesium hyperfine	9.19×10^9 Hz	an atomic phase	the second’s definition
Kaxion line	1.95×10^9 Hz	the dark condensate	the GGA Hessian, ringing
Hubble rate	$\sim 2 \times 10^{-18}$ Hz	the horizon scale	the interval, read as a rate

Two remarks. *First*, the ladder’s top three rungs are genuine circle returns — phases that come back — while the bottom rung is not a return at all: H is the interval wearing a frequency’s units, which is precisely why it *runs* (the Hubble “constant” was never constant) while the true ticks do not. A century of cosmological confusion about H is, on the anatomy, a category note: three of these rows are clocks, one is an odometer. *Second*, the thermal companion: the ratio of the shore’s period to the age, β/t , falls monotonically down the descent — the universe becomes ever more classical — with today’s value $\hbar\beta = 2.80$ ps against an age of 4.35×10^{17} s: the quantum tick and the cosmic arrow now twenty-nine orders apart, and the separation itself a derived function of the descent (Arisaka, 2026, P5-CPT; Arisaka, 2026, A5-GDOS).

36.5 The age ledger, line by line

Equation (45) closes an audit, and the three lines deserve their provenance because each is a different kind of number. *The launch segment* (36.1) runs from the Planck time to the end of reheating: it is the derived launch of (Arisaka, 2026, A10-Cosmos) — the plateau’s $N^* = 52.6$ e-folds plus the reheating match at the derived T_{rh} — converted to clock e-folds. *The radiation segment* (91.6) is standard kinematics run on the inherited inventory: the radiation-era clock $t = 2.42 g_*^{-1/2} (\text{MeV}/T)^2$ s integrated from reheating to equality with the cohort’s $g_*(T)$ transport — the longest and most checkable line, and the one whose slope the chronology figure displays as exactly 2. *The matter-plus-vacuum segment* (12.5) runs the derived $H(t)$ of the π -locked inventory from equality to today — the shortest line, and the only one that feels the terminus. Sum: 140.24, against nothing — there is no measured “age in Planck e-folds” to fit; the number simply is what the descent’s clock reads, assembled from three regimes with no dial among them. The flag then sits beside it exactly as the discipline requires: $140.24 = 4K \times 1.0017$ is recorded, not spent — the compression is either the e-fold budget campaign’s future theorem or a coincidence to be retired, and the ledger’s three lines are sound either way.

36.6 The chronology, tabulated

Figure 38 deserves its numbers in a form the reader can check by hand. The table below lists the epochs of the derived history in both bookkeeping conventions the cohort uses (the cosmology paper anchors r at the

corridor entrance; the proton companion at $M_{\text{Pl}}/2$, where the lock sits at $r = K$ exactly), with the boundary clock in e-folds of Planck times (Arisaka, 2026, A10-Cosmos; Arisaka, 2026, P5-CPT) — see Table 15.

Table 15: The descent’s timetable: eight epochs located on the interval by the depth coordinate r , with the lock at $r = K$, and dated on the boundary clock in e-folds of the Planck time. Reheating opens the interval’s account at $r = 19.13$; the lock crossing sits at $r = 35.00 = K$ exactly, the gate of Problem 11; and the electroweak scale, the QCD transition that delivers the Kaxion’s mass, nucleosynthesis, matter–radiation equality where the slope turns from 2 to $3/2$, recombination and today follow at 38.18, 45.11, 50.16, 64.20, 65.34 and 72.34. The last row closes the ledger at $\ln(t_0/t_{\text{Pl}}) = 140.24$.

Epoch	r (lock at K)	$\ln(t/t_{\text{Pl}})$	Note
launch (reheating)	19.13	36.11	the interval’s opening act
lock crossing	35.00	67.93	$= K$: the gate of Problem 11
electroweak	38.18	74.24	the agent’s scale
QCD	45.11	88.99	the Kaxion’s mass delivery
nucleosynthesis	50.16	99.28	the first nuclei
equality	64.20	127.71	the kink: slope $2 \rightarrow 3/2$
recombination	65.34	129.72	two quantities (§36.7)
today	72.34	140.24	the ledger’s close

The reader should run the check the figure invites, and should get the right answer for the right reason. Between adjacent radiation-era rows $\Delta \ln t / \Delta r$ reads 2.005, 1.984, 2.128, 2.038 and 2.025: five segments, no fit, and a straight line to two percent except across the QCD transition, where it runs 6.4% high. That departure is not slack in the derivation but physics the derivation contains — $t \propto g_*^{-1/2} T^{-2}$, and $g_*(T)$ falls sharply through the transition, so a clock calibrated on the radiation temperature must dress the exponent exactly there. The last two rows are matter-era and belong to the $3/2$ branch, not to this check; a reader who includes them will get 1.763 and 1.503 and should. The lock’s position at exactly $r = K$ in the second convention is the cleanest single display of the gearbox: the deepest event of particle physics sits at an integer of the circle, an e-fold count of the interval — one number, both fibers.

36.7 Two quantities at recombination: a discipline, not a detail

One methodological sharpening from the chronology work belongs in the main line, because it is a template for how the anatomy keeps its books (Arisaka, 2026, P5-CPT; Arisaka, 2026, A10-Cosmos). The recombination era carries *two distinct quantities* that a careless reading fuses. The *corridor switch* $z_{\text{sw}} = e^7 = 1096.6$ is topological: the ledger integer J in the exponent, exact, owned by the circle — it marks where the descent’s corridor changes regime, and it cannot move. The *atomic decoupling* $z_{\text{dec}} \approx 1090$ is physical: derived through the atomic chain (Saha physics, the hydrogen ladder) with zero-parameter agreement at the 0.11–0.16% level raw — owned by the boundary’s atoms, measurable, and the registered falsifier F7 (kill: measured z_{dec} off the atomic chain by more than 0.5%) is the *atomic* quantity, observable-only. The two sit 0.006 e-folds apart — 0.6% in z , under a tenth of a percent in the exponent — which is exactly why they must never be quoted as one number, and the cohort’s discipline is to name which is which at every site. The template generalizes: wherever the anatomy places a circle integer near a boundary observable (the switch and the decoupling; the base rung $\Xi_{\text{cap}} = K$ and the window’s lower edge; the lattice phase and the measured δ_{PMNS}), the exact quantity and the measured quantity are kept as two entries, compared but never fused — because

the comparison is the physics, and the fusion would be numerology.

36.8 What time is not

The definition of §36.1 gains sharpness from three contrasts with the standard alternatives, each stated structurally and without polemic.

Not the block. The block-universe reading takes relativity’s four-dimensional description at face value and concludes that passage is perspectival — nothing happens; all events simply are. The anatomy locates precisely what the block captures and what it misses: the block is the *circle’s* truth — the books, complete and tenseless — but the world contains a second fiber the block does not represent, and the reading of the books is as physical as the books. The runtime is not a perspective on the block; it is a semigroup the block does not contain. Passage is not an illusion; it is the interval.

Not thermal. The thermal-time tradition derives an arrow from coarse-graining: entropy grows because we describe imprecisely. The anatomy inverts the dependence: the interval’s one-wayness is prior to any observer’s resolution — the descent would run, deposit, and weld with no coarse-grainer anywhere — and the statistical arrow is the boundary’s shadow of the geometric one (Arisaka, 2026, A5-GDOS). This is why the cohort’s arrow does not fluctuate, reverse in small systems, or depend on initial-condition stipulations: it was never statistical.

Not emergent-from-timelessness. Canonical quantum-gravity traditions treat time as emergent from a timeless fundamental state. The anatomy agrees that boundary time is derived — it is the exponential shadow of the descent, Eq. (44) — but what it is derived *from* is not timeless: the interval is a direction with an intrinsic one-way transport, and the derivation is a change of clock, not a birth of change. The emergence tradition’s hard problem — extracting an arrow from a stateless wavefunction — does not arise, because the arrow was never absent from the fundamental description. Time is derived, but its direction is bedrock.

36.9 The measurement arrow

The laboratory meets this Part not in cosmology but on the bench: every measurement has a before and an after, and no interference ever resurrects a registered outcome. On the anatomy this is the same fact as Eq. (44) at small scale (Arisaka, 2026, A8-QM): the coherent half of quantum mechanics — superposition, interference, unitarity — is circle-side (the unread phase), while registration is an interval-side write — one-way because the fiber it is written along has no inverse transport. A record is *real* because it is written along the fiber that carries no phase (Part II), and *permanent* because its content is deposited in quantities the other fiber protects. The measurement problem, in its sharpest form — *why does a reversible theory produce irreversible events?* — receives the anatomy’s standing answer: the theory’s books are reversible; its reading is not; and a measurement is a read. The Born rule itself is carried by the cohort at the relaxation level — produced by the boundary law’s own dissipation, with the field-grade representation step the one named analytic residue — and this paper inherits that status verbatim (Arisaka, 2026, A8-QM).

The link back to Problem 2: the runtime that reads — the interval’s agent among the interactions — is not an abstraction. It has a name in the particle-physics tables, and the name is *the weak interaction*.

37 Problem 14. The Definition of Energy, Mass, and Entropy

37.1 Three household words without definitions

Physics' three most-used quantities are its least defined. Energy is introduced as “the capacity to do work,” then redefined in every subfield until only the conservation law remains — at which point the definition has become circular: energy is the thing that is conserved. Mass is worse: inertial resistance, gravitational charge, rest energy, a Yukawa coupling to a condensate — four glosses, coordinated but not unified, none answering a child's version of the question (*what is it that a kilogram has?*). Entropy is the strangest of the three: disorder to the public, phase-space volume to Boltzmann, missing information to Shannon's heirs — an objective law of nature built, apparently, on a subjective measure of ignorance. All three work flawlessly in calculation. None can say what it is. The anatomy's offer: one definition per structure — the tick, the address, and the write.

37.2 Energy: what the tick is worth

Noether located energy long ago: it is the conserved charge of time-translation symmetry. The anatomy supplies the missing referent — *which* time, and why symmetric. The tick is the circle's (Problem 13): repetition, phase returning to phase, and the symmetry of the tick — one moment of the cycle as good as another — is exact because the circle has no marked point. Energy is therefore *what the symmetry of time is worth*: the Noether price of the circle's indifference, which is why it is conserved absolutely (the circle cannot lose its symmetry), why it is the generator of phase rotation ($E = h\nu$ is not an analogy but the definition — energy *is* the tick rate, priced by the circle's constant $\hbar$), and why the first law of thermodynamics is the circle's ledger, with nothing one-way anywhere in it (Arisaka, 2026, A5-GDOS; Arisaka, 2026, P5-CPT). The child's question has an answer: what a joule measures is *how fast a system's phase turns*.

37.3 Entropy: what the arrow has read

Entropy belongs to the other fiber, and its subjectivity puzzle dissolves there. The runtime writes — one-way registrations, priced and unpriceable-back — and *entropy is the count of the writes*: what the arrow of time has read, the data-processing ledger of a semigroup. This is Boltzmann's and Shannon's measure seen from behind: phase-space volume and missing information both *quantify* the ledger, but the ledger itself is objective — writes happen, observed or not, because the projection is always on (Problem 1). That is why the second law is exceptionless without being statistical (nothing about the interval repeats, and the projection along it has no inverse), why entropy never decreases globally (there is no inverse write), and why the “subjectivity” was an artifact of reading the bookkeeping as the event: an ignorant observer counts the ledger coarsely, but the ledger was written by the runtime, not the observer. The famous tension between the two laws — exact conservation against relentless dissipation — is no tension at all: *the first law is the circle's ledger and the second is the interval's; a group and a semigroup do not contradict, they divide the labor*.

37.4 Temperature: where the ledgers exchange

The two currencies meet at one window. Temperature, in the cohort's KMS reading, is *where the interval meets the shore*: the thermal state's imaginary period is the exchange rate at which circle-currency (energy) converts to interval-currency (entropy), and the conversion fee is the familiar $T dS$. The Boltzmann constant is then the boundary's unit-fixing for that exchange (the thermodynamic member of the GU-5 pentad, §15), and cooling is descent: the exchange rate falls monotonically down the one-way history, which is why the

early universe traded energy for entropy furiously and today’s universe barely trades at all — the β/t ledger of §36.4, the universe growing ever more classical.

Figure 39 draws the window itself.

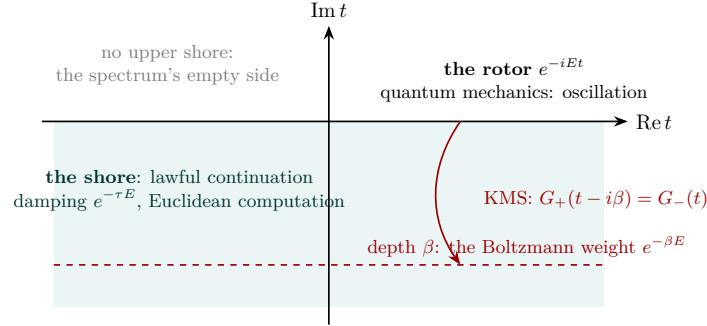


Figure 39: The shore, drawn (reproduced from Arisaka, 2026, P5-CPT). The exchange window where the circle’s ticks and the interval’s writes trade: the one-sided energy spectrum makes the boundary’s equilibrium state thermal (the KMS condition), and “temperature” is the window’s width — defined wherever tick-worth is exchanged for write-count at a steady rate, from one trapped ion to the de Sitter horizon. This is Problem 14’s temperature section in one picture: not a property of substance, but of the meeting of two ledgers.

37.5 Mass: the address a class wears

Mass is the two fibers jointly, and the three portraits of §31.6 are its definition by exhibition. What a particle *is* — its charge, spin, representation, its identity — is a circle-side class; what it *weighs* is the interval-side address of that class: the terminus of a descent for the electron, the binding of a weld for the proton, the Hessian of an attractor for the Kaxion. Three consequences, each an old puzzle: (i) identical particles have exactly identical masses, with no enforcement mechanism, because one class has one address; (ii) every mass formula in the codebook is an exponential dressed by integers (Problem 4), because addresses are depths; (iii) $E = mc^2$ becomes a dictionary entry rather than a mystery — a mass is a tick rate (the Compton frequency, $mc^2 = h\nu_C$: the class’s own clock, §36.4), so rest energy is the worth of a particle’s standing tick, and converting mass to energy is releasing the tick from the class that carried it. The kilogram’s answer: what a kilogram has is *a phase turning at 1.4×10^{50} revolutions per second, held by classes that cannot leak*. Figure 40 places the household words on the anatomy: each currency at the structure that defines it.

The three definitions, each as its equation. The tick’s worth:

$$E = h\nu, \quad (47)$$

energy is h times the rate ν at which the circle’s phase turns — not analogous to, but *definitionally* the price of phase rotation, with h the conversion constant (Step A). Read $E = mc^2$ through it: a mass m is a standing tick rate $\nu = mc^2/h$ — what a kilogram *has* is phase turning at $\sim 10^{50}$ revolutions per second — and “mass” is the address a class wears, the tick rate at which its identity idles. The write count:

$$S = k_B \ln W, \quad (48)$$

Boltzmann’s relation, with W the number of microscopic configurations compatible with the registered macrostate and k_B the unit conversion. On the anatomy $\ln W$ counts the boundary’s unread pages — what

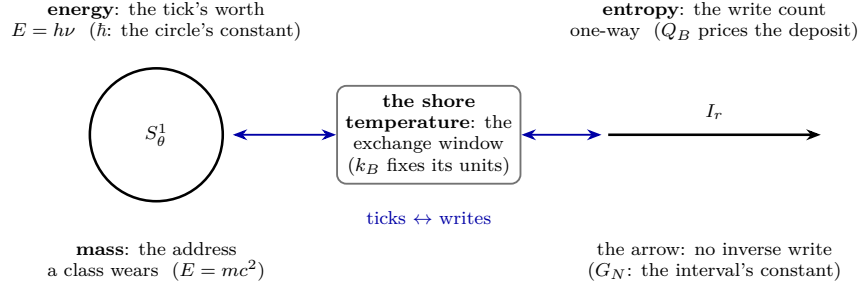


Figure 40: The currencies, located. Energy is the circle's charge (the tick's worth), entropy the interval's tally (the write count), temperature the window where the two ledgers exchange, and mass the descent address a holonomy class wears. Each currency comes with its unit-fixing constant, one per structure — which is why setting $\hbar = c = G_N = k_B = 1$ costs nothing: the constants were conversion rates all along.

has been registered *about* a system versus what would fully specify it — and the second law is Eq. (14) in thermodynamic clothing: the write count cannot decrease because there is no inverse write, and each erasure is priced by Eq. (8). The bridge to Problem 16, stated here so the currencies arrive there ready:

$$S_{\text{BH}} = \frac{k_B c^3 A}{4 G_N \hbar}, \quad (49)$$

the Bekenstein–Hawking entropy — an entropy that is an *area* A (the horizon's), divided by four Planck areas. Note which constants appear: $\hbar$ (the circle's), G_N (the interval's), k_B (the window's) — the only formula in physics that spends all three at once, which on the anatomy is no accident: a horizon is where all three ledgers meet.

37.6 Three worked examples

The pendulum and the atom (energy as tick-worth). Why is an excited atom's energy discrete? Because energy is the tick's price and the tick is a closed circle: the electron's phase must return around its orbital, whole turns only, so the tick rates — and with them the energies — come in steps. $E = h\nu$ across the board: a laser's joules are a phase-turn count, a battery's charge a winding stock. Nothing about “capacity to do work” explains the discreteness; the circle does, in one clause.

The expanding gas (entropy as write-count). Open the partition and let a gas fill the doubled box. What increased? Not disorder in any visual sense — the molecules were always a blur. What increased is the ledger: the expansion wrote the molecules' new reachability into the runtime's books, one-way (no unitary trick refolds the gas), and $\Delta S = Nk_B \ln 2$ prices exactly those writes. Maxwell's demon closes on the same line: the demon must *register* molecular data to sort, its registrations are writes, and Landauer's toll on their eventual erasure pays the second law in full. The law was never about knowledge; it audited events.

Annihilation (mass as address). An electron meets a positron; two photons leave with 2×511 keV. In the anatomy's grammar: two mirror readings of one class met, their class labels canceled (windings summing to zero), and the address each carried — the standing tick of $m_e c^2$ — was released as free ticks (photons: pure circle-currency, no class to hold an address). $E = mc^2$ is the dictionary of that event: *rest energy is the worth of a class's standing tick*, and matter–energy conversion is class-release, lawful exactly where the ledgers (charge, lepton number — circle books) permit.

37.7 The currencies through cosmic history

Run the definitions down the chronology of Problem 13 and the thermal history of the universe becomes a currency report. At the launch's end, reheating converts the roll's stored circle-currency into the hot bath: energy abundant, ledger young, the exchange window (T) blazing. Through the radiation era the interval writes furiously — every scattering a registration — and the entropy ledger swells to its famous 10^{90} ; the exchange rate falls as $T \propto e^{-r}$, cooling-as-descent. At the matter era's freeze-outs, circle-currency locks into classes (nuclei, atoms: addresses occupied, Problem 12's vaults sealed), and the writes slow. Today the exchange window has cooled to 2.7 K, the β/t ratio of §36.4 has fallen twenty-nine orders, and the future is the ledger's closing statement: a de Sitter universe, writes asymptotically ceasing, energy books frozen, entropy books full — *the first law's fiber still perfect, the second law's fiber finally quiet*. Heat death, in the anatomy's language, is not the victory of disorder; it is the completion of the reading.

37.8 Three classic strains, relieved

The definitions earn their keep where the textbook glosses strain. *Gravitating systems have negative heat capacity*: feed energy to a star cluster and it cools — a scandal for “energy as capacity” intuitions and the source of endless paradox-mongering. On the anatomy the strain releases: gravity is the integrator, not a keeper (Problem 2) — it prices configurations along the interval rather than storing circle-currency — so gravitational “thermodynamics” was never the exchange of a bath but the bookkeeping of descent, and the negative sign marks exactly where pricing, not storing, dominates. Its extreme case is Problem 16's horizon. “*Where is the gravitational field's energy?*” — relativity's oldest bookkeeping quarrel: no local tensor exists. The anatomy's reading: energy is the tick's Noether charge, and the tick is the circle's — global phase structure — so energy localizes exactly as well as the tick does and no further; the famous non-localizability is not an accounting failure but a category note, and the global statements (ADM-style totals) are where the definition natively lives. “*Is mass just energy in disguise?*” — the popular collapse of the two. The grammar keeps them distinct and related: energy is circle-currency in general; mass is that currency *on deposit in a class* — addressed, guarded, identical across copies. A photon has energy and no mass because it has a tick and no class; an electron has both because its tick is held. The three strains share one moral: the household words wobble precisely where one fiber's bookkeeping is asked to describe the other's business — and firm up the moment the ledgers are sorted.

37.9 The pentad, and why natural units are natural

The definitions close the loop with the constants that measure them (§15; Arisaka, 2026, A4-Euclid). Each currency has its unit-fixing constant, and each constant belongs to a structure: $\hbar$ prices the tick (the circle's constant — energy per unit phase rate); G_N prices the descent (the interval's — the integrated warp volume, why gravity's constant alone is tied to irreversibility); c converts the stage's directions; k_B fixes the exchange window's units; and Q_B fixes the information deposit's. Setting $\hbar = c = G_N = k_B = 1$ — the physicist's “natural units” — is then not a computational trick but a confession the anatomy makes explicit: the constants were never independent facts to explain, but the conversion rates between one geometry's directions, and choosing the geometry's own units makes them disappear *because they were units all along*. What remains when the units are natural is exactly what this paper's Problems compute: the dimensionless ledger — integers, π 's, and depths.

37.10 Seminar questions

Is energy conserved in an expanding universe? The famous subtlety — redshifting photons “losing” energy — sorts cleanly. Energy is the tick’s charge, exact wherever the tick’s symmetry stands; the expansion is descent — the interval repricing the exchange window as history proceeds — and a photon’s redshift is its tick read against a later, cheaper window, booked lawfully in the chronology’s ledger (Problem 13), not leaked from the circle’s books. The general-relativistic statement (no global conservation law without a timelike symmetry) is the same sentence in the older dialect: where the descent moves the window, the tick’s worth is repriced, and the audit that balances is the ledger’s, not the naive sum’s.

Could entropy ever decrease? Locally and apparently, always (a refrigerator); globally in the write count, never — there is no inverse write. The Poincaré recurrences that haunt closed-system statistical mechanics need the return of a phase-space trajectory; the runtime is not a closed trajectory but a semigroup, and Problem 15’s “large circle” answer applies verbatim: recurrence is a property the interval does not possess.

What is temperature at, say, a single atom? The exchange window is defined wherever writes exchange tick-worth — which needs an ensemble of exchanges, not a large body. A single trapped ion in a laser field has a perfectly good temperature the moment its ticks and writes reach steady exchange; the anatomy’s definition is operational at one atom and at one universe (the de Sitter temperature of Problem 7’s terminus), because it was never about substance — only about the meeting of two ledgers.

37.11 The fourth currency, and the audit

The information age added a fourth quantity to the household — the bit — and the anatomy’s ledger has a column waiting. A stable bit is holonomy-class data (memory on the circle); erasure is an interval-side write (Landauer’s bound as the toll, [Landauer, 1961](#)); and the exchange rate between energy-per-winding and energy-per-qubit is the Arisaka constant Q_B , fixed by ledger integers rather than by any bath — temperature-independent where Landauer’s price is not ([Arisaka, 2026, A7-Qi4](#)). With it the currency system closes: energy (the circle’s), entropy (the interval’s), temperature (the exchange window), mass (the address), information (the deposit) — five household words, one anatomy, and a single audit question for all of them, which the cohort’s papers pose quantitatively from the laboratory to the de Sitter horizon: *do the books balance?* So far — from calorimetry to black-hole thermodynamics to the cosmic ledger of Problem 13 — they do.

Grade and kill, consolidated. Energy/entropy identifications: theorems of the boundary law. The mass grammar: codebook grades per entry. Q_B : the information pillar’s grades. Kill: a one-way failure of energy conservation; a repeating entropy ledger; a mass off the address grammar at precision; a free erasure. The three household words, on the anatomy: *energy is what the tick is worth; entropy is what the arrow has read; mass is the address a class wears* — and none of the three was ever mysterious; each was half of a pair, described for a century as if it were whole.

Figure 41 closes the Part’s audit with the four currencies read off one current.

38 Problem 15. The Landscape and Multiverse Problems

38.1 How explanation went environmental

The road to the multiverse was paved with reasonable steps. String theory’s flux compactifications appeared to admit an enormous discretuum of vacua — the famous 10^{500} , a figure whose comparability with a count

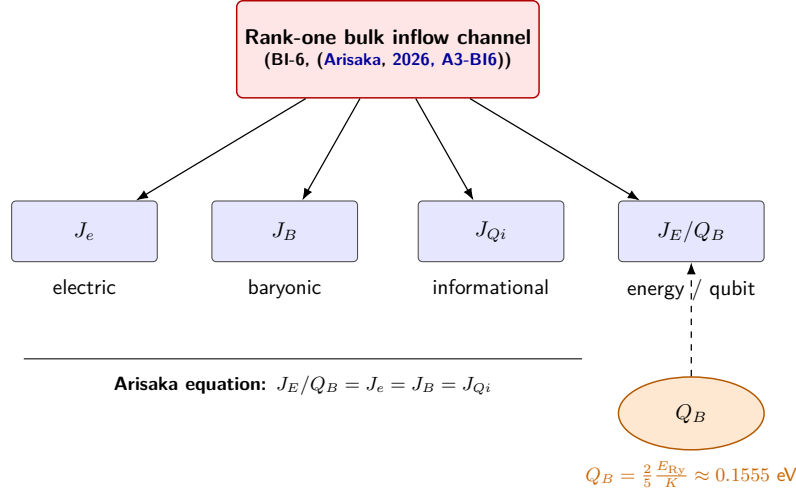


Figure 41: The Arisaka equation: one current, four readings (reproduced from Arisaka, 2026, A9-SM). The bulk carries a single conserved current, and the boundary reads it in four currencies at fixed exchange rates: $J_E/Q_B = J_e = J_B = J_{Qi}$ — energy flux priced by the Arisaka constant Q_B , elementary-charge flux, baryon flux, and information flux, equal because they are one bookkeeping seen through four windows. The pentad of unit-fixing constants (Step A of Part II) is this figure’s exchange board, and Problem 14’s “fourth currency” is the J_{Qi} column.

of continuous parameters §38.3 disputes on the landscape’s behalf — each with its own constants; eternal inflation appeared to provide a mechanism for populating them all; and the cosmological constant’s smallness (Problem 6) appeared to have no dynamical explanation but a ready anthropic one — observers arise only where the vacuum permits galaxies, so we find ourselves, unremarkably, in a rare habitable pocket. Assemble the steps and the constants of nature become environmental facts, like the Earth–Sun distance: not derivable, only conditioned upon. Many physicists accept this soberly; many others regard it as the abandonment of the explanatory program — and the debate has been sharpened by the measure problem (in an infinite multiverse, every probability depends on how one regularizes the infinities, and no canonical regularization exists). The question of this Problem is not whether the multiverse is emotionally satisfying. It is whether the premises that made it *necessary* hold.

38.2 The premise: a hat

Strip the construction to its load-bearing premise: explanation went environmental because theory seemed to offer a *hat* — a vast set of equivalent minima with no principle of choice. Given a hat, something must draw from it; a drawn constant is an accident; an accident plus observership is anthropics; anthropics plus a mechanism of drawing is a multiverse. Every step after the hat is close to forced. The anatomy therefore attacks the hat, and only the hat.

38.3 The landscape’s case, in the landscape’s own voice

A contrast is only worth drawing between positions stated at full strength, and the landscape’s case is usually reported by its critics. Before the anatomy answers, here is that case as its advocates make it, with the concessions this paper owes it.

The headline contrast is a category error, and a prepared opponent will say so first. Setting “ 10^{500} vacua” beside “zero free parameters” puts two different kinds of quantity in one column: a count of discrete solutions

against a count of continuous dials. They are not commensurable, the vacuum figure is itself unstable across constructions by hundreds of orders of magnitude, and — the point that costs the most — string theory makes the *same* zero-continuous-parameter claim this framework does. On the axis this paper advertises, the two programs agree. The disagreement is about whether the discrete choice is made by selection or forced by arithmetic, which is a smaller and more interesting difference than the raw contrast suggests.

The vacua were found, not wanted. A theory of quantum gravity was not constructed in order to have many solutions. The multiplicity was discovered, by people who would have preferred one, and published because that is what one does with an unwelcome result. Any imputation of convenience is unearned.

Results survive the landscape reading that this paper relies on or must respect. The bulk–boundary dictionary (Maldacena, 1998) is the closest structural relative of this framework’s own projection, and the exact statistical-mechanical count of an extremal black hole’s microstates (Strominger and Vafa, 1996) is the strongest existing evidence that horizon entropy counts something. Both stand whether or not the landscape is the right reading of the framework that produced them.

The tradition has one dated forward commitment, and it got it right. Weinberg (1987) predicted the order of magnitude of the cosmological constant from selection considerations a decade before it was measured, and was closer than any first-principles calculation then available. A paper that asks to be judged by dated forward commitments — as Part VII does — cannot dismiss the one dated forward commitment its opponent got right. §38.7 rereads that success in this framework’s terms; the concession has to stand on its own first.

And the deepest disagreement is not settled by either side asserting it. On the environmental reading, explaining a constant means exhibiting a mechanism that permits it and a selection effect that makes our observing it unsurprising. On this paper’s reading, that is a weaker thing than exhibiting a mechanism that *compels* it. The difference shows up not in elegance but in what can be lost: a framework of the first kind absorbs a surprising measurement by moving within its own space of vacua, and a framework of the second kind cannot. Which is the right standard of explanation is a real open question in the philosophy of physics, and Susskind (2003) states the opposing answer clearly enough that this paper will not pretend it has been refuted. What follows is not a refutation. It is the observation that the construction needs one specific premise, and an argument that this geometry does not supply it.

38.4 The anatomy’s answer: a dial, and one playback

The compact sector’s vacua are not a continuum and not a discretuum of equivalents: they sit at ledger-rational angles — a *dial* — and the scan across the dial has a unique winner; the GFF landscape has a deepest floor per stratum (the GGA), unique on the admissible strata by Frankel–Atiyah (§18); and the semigroup reads once, with no re-draw. Between them the three mechanisms remove every point where a draw could occur: no continuum to fall through, no degeneracy to break by accident, no second chance to differ. The constants are then not environmental but *arithmetical* — the codebook of Problem 4, the same in every region (Problem 8, Horizon 3) and in every rerun. The landscape problem, on the anatomy, is not solved but *unfounded*: the hat the construction needed is, in this geometry, a dial with a groove — and one groove plays one playback. Figure 42 sets the two explanatory architectures side by side — the hat and the groove.

38.5 The multiverse, unemployed

What then of other universes? Here the anatomy’s conclusion is deliberately modest, and stronger for it. It does not assert that nothing exists beyond our horizon volume, or that the bulk admits no other realizations; metaphysical exclusivity is not a physics claim. It asserts *unemployment*: the explanatory work the multiverse was hired to do — accounting for the values of the constants — does not exist in this framework, because the constants are theorems, not draws. Other players, if any, play the same record; postulating them explains

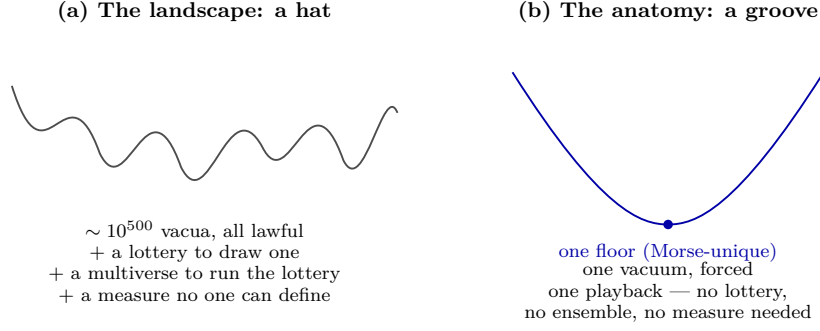


Figure 42: The hat and the groove. (a) The environmental architecture: a vast landscape of lawful vacua, a random draw, and an ensemble to give the draw somewhere to happen — with the measure problem as the permanent bill. (b) The anatomy’s architecture: the determinism triad’s unique floor, on the condition §18 states. The multiverse is not refuted here; it is *unemployed* — the constants it was hired to explain are forced, and a lottery with one ticket needs no drum.

nothing our own playback does not already explain, and the measure problem evaporates unhired. This inverts the usual burden honestly: the multiverse is not refuted (one cannot refute an unemployment), but every argument *for* it that routes through “the constants must be selected somehow” loses its premise. What would re-employ it is exactly what would kill this Problem’s answer: evidence of a drawn constant.

For the record, the two architectures as bookkeeping. The landscape requires a triple,

$$\{V_i\}_{i=1}^{\sim 10^{500}}, \quad \text{a populating dynamics,} \quad \text{a measure } \mu \text{ (undefined),} \quad (50)$$

— an enumeration of lawful vacua, eternal inflation to realize them, and a probability measure over an infinite ensemble, the third being the unpaid bill: every regularization of the infinity gives different predictions, and no principle selects one. The anatomy requires a single statement,

$$F'(\varphi^*) = 0, \quad F''(\varphi^*) > 0, \quad \varphi^* \text{ unique on the admissible stratum,} \quad (51)$$

— the GFF landscape has one stationary point that is a minimum, and the Morse analysis of Arisaka (2026, A6-GRIP) supplies its uniqueness on the hypotheses that analysis names (§18), so “which vacuum?” is a computation with a condition attached rather than a draw — which is still a different kind of object from a lottery. The asymmetry of explanatory cost is the argument: the first architecture buys the constants’ arbitrariness at the price of an undefined measure; the second buys their necessity at the price of being killable by any single constant that misses (Eq. (26)’s measured columns are the running audit).

38.6 What honestly remains anthropic

The cohort keeps one residue on the anthropic books, and this paper repeats it in full view (§31.5): the *timing* of observership — why the odometer reads $\sim 4K$ e-folds when observers arrive — is bounded by the geometry (the corridor’s shape is derived; habitability’s window within it is computed) but not yet derived, and the e-fold budget campaign is its named would-be closure. The discipline matters: a framework that dissolves the landscape has every incentive to overclaim, and the honest ledger is what distinguishes “the constants are forced” (claimed, graded, staked) from “everything about our situation is forced” (not claimed). W1’s four words carry the exact register: not contingent, not lucky, not designed — *forced* (Arisaka, 2026, W1-Symmetry) — said of the structure, and of the structure only.

38.7 Weinberg’s success, reread

The anthropic tradition owns one striking success, and honesty requires facing it squarely: in 1987 Weinberg argued that observers require galaxies, galaxies require the vacuum energy not to dominate before structure forms, and therefore a landscape-distributed Λ should lie below an anthropic ceiling — years later, dark energy was found some two orders of magnitude beneath that ceiling, of the order the argument made room for. On the landscape reading this is evidence of environmental selection. The anatomy rereads it without discarding it: the vacuum’s *value* is geometric (the seesaw and the Hopf share, Problem 7), but the *coincidence structure* Weinberg exploited — that the crossover epoch and the structure-formation epoch are near neighbors on the corridor — is a real feature of the derived geometry, which is exactly why an anthropic argument ranged over it could bracket the value. Anthropic reasoning, on this account, is a valid *consistency probe* of any world containing observers — it correctly locates where in a derived history observers can sit — and becomes an *explanation* only if the value is genuinely drawn. Whether it was drawn is not a matter of taste; it is the isocurvature-and-constancy scoreboard of §“How this Problem dies,” and the scoreboard currently reads: not drawn.

38.8 The measure problem, dissolved rather than solved

The multiverse’s internal crisis deserves its own paragraph, because its dissolution is a clean corollary. In eternal inflation every outcome occurs infinitely often, and predictions require a measure — a way of comparing infinities — on which no consensus exists after decades: the youngness paradoxes, Boltzmann-brain dominances, and cutoff-dependences are the literature’s own catalog. The anatomy does not solve the measure problem; it *unasks* it, twice over. Once dynamically: the launch is a single traverse of a semigroup — eternal self-reproduction is a re-ascent the fiber cannot perform, so the infinite ensemble is never generated. And once explanatorily: predictions here are theorems about the one playback, needing no comparison class — the probability apparatus that a multiverse must build from a measure, this framework inherits from the Born chain of Problem 1, relaxed into rather than postulated. A problem that exists only inside a framework is evidence about the framework; this paper scores it accordingly, and no further.

38.9 The catalog of tunings, triaged

The anthropic literature’s stock-in-trade is the catalog of apparently tuned quantities — the six-numbers lists, the fine-tuning compendia: nudge this constant and no galaxies, nudge that one and no chemistry. On the anatomy the catalog is not denied; it is *triaged*, entry by entry, into the Problems of this paper where each tuning dissolves into structure: the strength ratios and the weak scale (the hierarchy) — addresses, Problem 6; the vacuum energy — the seesaw’s depth and the Hopf share, Problem 7; the strong-CP angle — the attractor’s floor, Problem 12; the flavor textures and the matter excess — the chiral alphabet and the toll, Problems 9–11; the spectrum’s tilt and the sky’s flatness — the launch, Problem 5; the constants’ constancy itself — the classes, Problem 8. What remains after triage is the residue already booked (the timing), plus the catalog’s real lesson, which the anatomy affirms: the world’s habitability is deeply enmeshed with its structure. The traditions differ only on the direction of explanation — selection reading structure from habitability, the groove reading habitability from structure — and they differ testably, because a groove’s entries hold in *every* region and rerun, while a selection’s hold only in ours. Each constancy bound, each isocurvature null, is a vote between the directions; the running tally is §“How this Problem dies.”

38.10 The landscape’s own standing

One more honest note completes the picture: the hat itself is contested territory. Whether string theory actually possesses 10^{500} stabilized de Sitter vacua is an open technical question — the swampland program within string theory itself argues that most effective theories admit no consistent ultraviolet completion, and some of its conjectures strain against de Sitter vacua altogether. The anatomy takes no side in that internal debate, but its structural position is worth locating: a one-groove geometry is, in effect, the *extreme swampland claim* — the assertion that consistency prunes the possibilities not to a large residue but to one. The burden that claim carries is exactly the codebook’s: it must derive, entry by entry, what others scan for — and Problem 4’s sheet is that burden, accepted in public. Between a landscape whose size is uncertain and a groove whose predictions are staked, the arbiter is not philosophy; it is the falsifier table.

38.11 Seminar questions

Is this just determinism, restated? It is determinism *located* — and bounded. The groove fixes structure: which layers exist, their constants, their attractors (the triad’s theorems). It does not preprogram what happens within a layer’s combinatorial freedom — histories, weathers, biospheres, choices — which the capstone’s layered reading shelters rather than schedules. The multiverse question only ever needed the structural half: constants are what selection was hired to explain, and constants are what the groove fixes.

If everything is forced, why do the constants LOOK arbitrary? Because addresses look arbitrary until counted. 137 looks like a lottery ticket until it is $2^J + N^2$; a seventeen-orders hierarchy looks tuned until it is thirty-eight e-folds of descent, thirty-five of them the ledger’s K ; the sheet of Problem 4 looked like dials for a century because its two fonts — labels and addresses — were read as one. Apparent arbitrariness is the normal appearance of unread structure; the discipline is to distinguish that claim (auditable, per entry) from its lazy cousin (“everything happens for a reason”), and the audit table is the distinction.

Doesn’t quantum randomness reopen the lottery? No: Born-rule outcomes randomize *within* the runtime’s statistics, not *over* the structure. No quantum event can relocate a vacuum, redraw a constant, or unwind a class — the dial, floor, and ledger sit in exactly the quantities measurement cannot deform (Problem 1). The lottery the landscape needed was structural; the randomness quantum mechanics provides is episodic; and the anatomy keeps the two in separate books by construction.

38.12 How this Problem dies

The groove account is falsifiable precisely where the landscape account is not, and the asymmetry is the point. *Any evidence of a drawn constant kills it*: a measured constant off its closed form beyond the declared dressing (Problem 4’s sheet); patch-to-patch variation of a protected quantity (Problem 8’s audits); axion-sector isocurvature — the lottery’s own signature — at any level (§31.7); or a demonstrated degeneracy of GFF floors on an admissible stratum, where Frankel–Atiyah forbids it. The landscape framework survives all such measurements equally well, which is its structural weakness; the groove stakes them all. **Grade:** the dial, floor, and once-only reading carry Part II’s grades; unemployment is a corollary; the timing residue is open, named. On the anatomy, the deepest question the multiverse was invented to answer — *why these constants?* — returns to the discipline that asked it: because $(1, 3, 5; 7, 35)$, because π , because e^{-K} — *because the groove*.

39 Problem 16. The Black-Hole Information Paradox

39.1 Fifty years of a paradox

In 1974 Hawking showed that black holes radiate thermally (Hawking, 1975); in 1976 he drew the devastating corollary. Collapse a pure quantum state into a black hole, let it evaporate, and the outcome is thermal radiation — a mixed state. Pure in, mixed out: information destroyed, in direct conflict with quantum mechanics’ unitarity. The half-century since has been a war of attrition among partial resolutions: information escapes in subtle correlations of the radiation (but how, across a horizon?); it survives in remnants (with pathological consequences); complementarity lets infalling and outside observers keep different books (until the firewall argument of 2012 showed the books collide — smooth horizon, unitarity, and effective field theory cannot all hold); and the island/replica computations of 2019–2020 recovered the unitary Page curve from semiclassical gravity, a landmark — while leaving the physical mechanism, in many practitioners’ own words, obscure. The state of play: nearly everyone now believes information survives; nobody agrees on where it was. The two Hawking results, as equations with their readings. A black hole of mass M radiates at temperature

$$T_H = \frac{\hbar c^3}{8\pi G_N M k_B} \approx 6 \times 10^{-8} \text{ K} \times \frac{M_\odot}{M}, \quad (52)$$

— colder for heavier holes (the inverse- M is why astrophysical holes are unobservably faint), with the same three-ledger constant structure as Eq. (49) — and carries the entropy $S_{\text{BH}} = k_B c^3 A / 4G_N \hbar$: one quarter of the horizon area A in Planck units. Together they fix the evaporation time ($t_{\text{evap}} \sim G_N^2 M^3 / \hbar c^4$, $\sim 10^{67}$ yr for a solar mass) and the schedule any unitary account must meet: the radiation’s entanglement entropy must turn over at roughly half the evaporation — the Page time — and return to zero at the end (Page, 1993). The paradox, restated against these equations: Eq. (52)’s spectrum is thermal, and a thermal spectrum carries no record; either the books balance by a mechanism the semiclassical calculation cannot see, or unitarity fails.

39.2 The anatomy’s diagnosis: a billing error

The paradox, on the anatomy, is a category mistake with a fifty-year pedigree: *it asked one object to be both fibers at once* (Arizaka, 2026, C3-BH). Unitarity, purity, conservation — the keeping — are circle-side obligations; thermality, irreversibility, evaporation — the spending — are interval-side behavior; and Hawking’s calculation, performed on the four-dimensional shadow where the two fibers are invisible, billed the spending against the keeping and found the account short. It was short because it was the wrong account. Sort the transaction by fiber and each half is not merely consistent but *obligatory*: everything the evaporation must conserve — charges, ledger integers, holonomy-class records — is deposited on the fiber no boundary operation can deform, which is why the information was never destructible in the first place; and everything thermal and one-way about the radiation is the interval doing the only thing a semigroup does. The Hawking temperature itself carries the signature: it is the shore periodicity of the KMS reading — *temperature is where the interval meets the shore* (Problem 14) — and a horizon is where that meeting is sharpest. Figure 43 fixes the geometry the paradox lives on.

39.3 Where the information always was

The paradox’s engine was the apparent absence of an environment: laboratory decoherence sends purity into unmonitored degrees of freedom, but the radiation “was all there was.” The anatomy names the missing register: the bulk behind the port. The compact and radial sectors are as physically real as a laboratory’s photon modes — they are where the books are kept — and the mixedness of the four-dimensional radiation

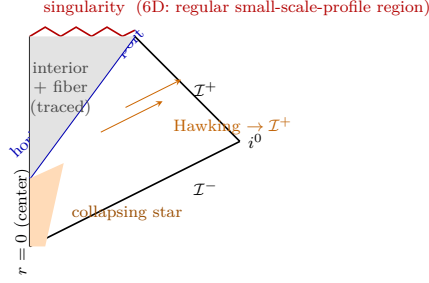


Figure 43: Collapse and evaporation, in the conformal diagram (reproduced from Arisaka, 2026, C3-BH). Time runs upward; every 45° line is null. The event horizon (blue) is a one-way OGGEF port: the exterior observer receives the Hawking radiation (orange) but cannot access the interior, which — together with the non-spatial fiber — is traced out. On the anatomy the classical singularity is a small-scale artifact, regular in the six-dimensional bulk, and the horizon carries no firewall because it is an ordinary 6D surface: the drama is in the books, not the geometry.

is the same benign bookkeeping every open system exhibits: purity gone into correlations with degrees of freedom the four-dimensional description never tracked. What was extraordinary about the black hole was never the physics; it was that geometry hid the environment so completely that physics spent five decades looking for it. On this reading the modern consensus is vindicated in substance and corrected in address: information survives — in the fiber ledgers, not in miraculous correlations threaded through the horizon.

Figure 44 draws the diagnosis.

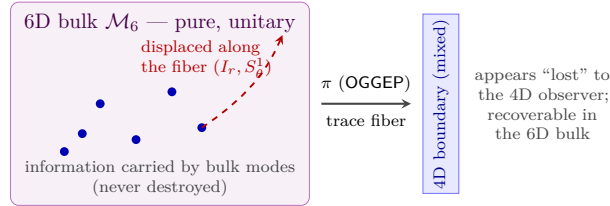


Figure 44: Information “loss” as displacement (reproduced from Arisaka, 2026, C3-BH). What falls in is not erased but *relocated*: the class data ride the circle’s register (inaccessible to the boundary observer, not absent from the bulk), while the interval’s channel prices their staged return through the radiation. The paradox’s “loss” is the distance between where the information is and where the exterior observer can read from — a bookkeeping displacement, closed on the Page schedule of Figure 45.

39.4 The Page curve as a reconciliation schedule

The island computations recovered the right curve; the anatomy supplies its mechanism in one sentence. The circle’s ledger — the conserved content the hole must return — is read out through the interval’s one-way channel at the rate the channel permits: early radiation is dominated by the channel’s thermal character (entropy rises), until the ledger’s remaining balance becomes the smaller book (the Page time), after which the readout is ledger-dominated and the entropy falls — *the circle’s ledger, read out through the interval’s channel*. The curve is a reconciliation schedule between two fibers’ books, which is why it is universal in shape and insensitive to microphysics: schedules of repayment depend on the balance and the channel, not on the furniture. And there are no firewalls: the 2012 collision arose from demanding that the horizon’s smooth

interval-side physics also carry the circle’s books locally; sorted, nothing at the horizon does the other fiber’s job, and the smoothness survives with the unitarity.

Figure 45 draws the schedule: the two accounts of the radiation’s entropy, and the turnover where the books begin to balance.

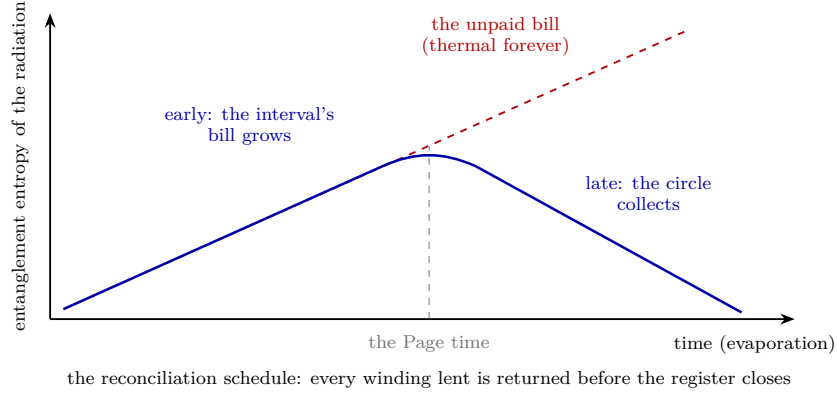


Figure 45: The Page curve as a reconciliation schedule. The dashed line is the billing error: entropy rising forever, a register that never pays. The solid curve is the audited account: the interval’s channel prices the outflow while the circle’s register holds the classes the hole must return, and from the Page time onward the returns dominate. The island computations of the last decade compute this curve gravitationally; the anatomy says *why* the books were always going to balance.

39.5 The two books, side by side

The billing error is easiest to see as an accountant would, with the transaction sorted into its two books (Table 16).

Read down either column and there is no paradox anywhere in it; read across — demand that the flux’s thermality be a property of the register, or the register’s unitarity a property of the flux — and the fifty-year literature reappears line by line. The area law itself sits naturally in the sorted books: the horizon’s entropy measures the capacity of the register behind the port — how much circle-side content the geometry can hold at that address — which is why it is an area (a boundary capacity) and not a volume, and why it obeys a generalized second law (register capacity plus channel writes never decreases: the two books’ joint ledger).

39.6 Complementarity and the islands, placed

The modern proposals slot into the sorted books with their achievements intact. *Complementarity* intuited the two books — infalling and external descriptions keeping different accounts — but drew the boundary between *observers*, where the anatomy draws it between *fibers*; the firewall collision arose exactly at observer-boundary crossings, and dissolves at fiber boundaries, which no observer crosses because no observer reads fiber coordinates (OGGEP). *The island formula* computes, from within semiclassical gravity, which degrees of freedom the radiation’s book must include to stay unitary — and its famous quantum extremal surfaces are, on this reading, the geometry’s own bookkeeping of where the register’s content transfers to the channel’s manifest: the islands *are* the reconciliation schedule, computed gravitationally. The anatomy honors the computation and supplies what its practitioners call missing — the mechanism: the books were always two, and the schedule reconciles them. *ER=EPR*-style proposals intuited that entanglement and geometry are one

Table 16: The information paradox as a billing error, sorted into its two books as an accountant would sort it. The circle’s book holds charges, ledger integers and class records; it is exact, unitary and indestructible; its entropy is the capacity of the register and its Page curve the balance remaining. The interval’s book holds the infall, the thermal flux and the shrinking area; it is one-way, dissipative and priced; its entropy is the count of the channel’s writes and its Page curve the readout executed. Hawking’s temperature appears in the second column only, as the shore periodicity of the channel. Fifty years of worry asked “where did it go?” of the first book and “why is it thermal?” of the second.

	The circle’s book (kept)	The interval’s book (spent)
What it holds	charges, ledger integers, class records	the infall, the thermal flux, the shrinking area
Character	exact, unitary, indestructible	one-way, dissipative, priced
Hawking’s T	—	the shore periodicity of the channel
The entropy	the capacity of the register	the count of the channel’s writes
The Page curve	the balance remaining	the readout executed
Fifty years’ worry	“where did it go?”	“why is it thermal?”
The answer	nowhere: it is class data	because channels are the interval’s

bookkeeping; the anatomy locates the bookkeeping on the compact fiber, where entanglement’s monogamy and the ledger’s integrality are the same discipline. Fifty years of proposals, on this reading, were each holding a true page of a two-book audit — and the audit needed only its anatomy.

39.7 Questions from the seminar

Does an infalling observer hit anything at the horizon? No. Smoothness survives because nothing at the horizon performs the other fiber’s job: the crossing is interval-side passage, the books are circle-side deposits, and the firewall demanded their collision only under the one-object assumption. The equivalence principle keeps its dignity; the ledger keeps its integers; they were never in competition.

Where, physically, is the register? Behind the port — in the compact and radial sectors over the horizon region — which is to say: not at a place on the four-dimensional map at all. Asking for its street address repeats the category slip of Problem 3’s sealed dial: fiber content has capacity and bookkeeping, not location in the shadow. The horizon’s area measures the capacity; that is as spatial as the register gets.

Is this a remnant scenario? No. Remnants park the information in a long-lived object with pathological pair production; here evaporation completes, the channel closes, and the books balance because the readout finished — the Page curve is the completion certificate, not a stay of execution.

Could the resolution be tested short of a black hole? In stages, yes. The mechanism — circle-kept content read through an interval channel — is Problem 1’s measurement chain at extreme redshift, and every laboratory audit of open- system exactness (analog horizons, engineered dissipative systems, the no-free-erasure bound of Problem 14) exercises the same bookkeeping the hole exercises violently. The black hole is the anatomy’s stress test, not its only appearance — which is exactly why I treat the paradox’s resolution as a consistency obligation rather than an isolated triumph.

39.8 The de Sitter cousin

Our own sky carries the paradox’s gentlest relative, and closing with it ties this Problem to the trio of Problem 7. The accelerating universe has a future event horizon — a permanent causal screen at $R_e = c/H_\Lambda$ — with its own Gibbons–Hawking temperature (Gibbons and Hawking, 1977) and its own entropy, the largest number in physics ($S_{\text{dS}} \sim 10^{122}$, whose e^{8K} face rides at flagged grade with the rest of the family). Every argument of this Problem transfers: the cosmological horizon is a channel, its entropy a register capacity, its thermality the shore’s — and the observer’s predicament inverts instructively: at a black hole we hold the register’s outside and watch the channel; inside de Sitter we *are* the register’s contents, and the terminus’s frozen books (Problem 7’s “the interval exhausted, the circle’s shares frozen”) are the Page-curve endgame seen from within. That one bookkeeping serves the gram-scale analog, the solar-mass hole, and the Hubble volume is the anatomy’s final word on the paradox: it was never about black holes; it was about what any horizon does to a two-fiber ledger — and every horizon in nature, so far, does it lawfully.

39.9 The stakes, and the audit

Black holes are where the anatomy’s two ledgers meet at maximum contrast, and the meeting is increasingly observational. The companion paper stakes its corrections and consistencies across the instruments of the decade — ringdown spectroscopy (LIGO/LISA), horizon-scale imaging (EHT), the analog-system entanglement measurements — and carries the de Sitter extension: the cosmological horizon’s entropy (Problem 7’s e^{8K} face, at its flagged grade) as the same bookkeeping at the largest address. The audit question is Problem 14’s, asked at the extreme: *do the books balance across a horizon?* The anatomy answers yes, names which book is which, and accepts the exposure. **Grade and kill, consolidated.** The resolution inherits the companion’s grades (Page-curve and no-firewall analyses, conditional as declared there). Kill: ringdown or imaging inconsistent with the staked corrections; a demonstration that the bulk register cannot carry the required capacity; or — the in-principle referee — any laboratory analog exhibiting true information loss in an open system’s exact books. The paradox, on the anatomy: *the circle keeps what the hole must return; the interval prices the return; and fifty years of debate audited the wrong fiber.*

Part VI in one paragraph, and what comes next

The arena, read on its own two fibers. Time is not one thing but a joint reading: the tick is the circle’s, the direction is the interval’s, and the two have been carried under one word since Newton, which is why neither an equation nor a statistical argument alone has ever produced an arrow. Energy, mass and entropy sort the same way — what a tick is worth, what an address costs, what the one-way writes have counted. The multiverse is not refuted but unemployed: a census that permits one bulk of one shape has no work for an ensemble. And the information that fell into a black hole was never lost, only entered on the other book. Sixteen problems are now behind us, each treated at its own grade. What remains is to ask what a single sentence could possibly have been doing in the load-bearing position of all of them. Part VII consolidates: one master table, one honest ledger of the weak joints, one falsifier table with dates, and one comparison of this reading against the programs it will be measured against.

Part VII

Discussion

What One Sentence Did with Sixteen Problems — Significance, Contrasts, the Honest Ledger, and the Ways to Be Wrong

40 The sixteen, consolidated: the master table

Parts III–VI are now behind the reader, and the paper owes its central claim in one place: sixteen problems, one structural sentence, each treatment with its mechanism, its sharpest quantitative face, its declared grade, and the measurement it dies by. Table 17 is that consolidation — the paper on one spread. Every row is developed at essay length in its Part; every grade is inherited from a parent paper; every kill condition reappears, dated, in Table 18.

Three remarks before the discussion proper. *First*, the mechanism column uses only two letters — there is no third ingredient anywhere in the table, which is the paper’s claim in its tersest form. *Second*, the grade column is heterogeneous, and that is deliberate honesty rather than weakness: a synthesis that claimed uniform grade D would be claiming what the parent papers do not. *Third*, the last column is non-empty in every row — there is no problem on this list whose treatment is unfalsifiable in principle. The qualification matters and §48 makes it: six of the sixteen have a named instrument and an era, and the rest are exposed through the shared ledger rather than on their own. A framework that stakes even the first six on dated channels is in an unusual position, and the paper would rather claim that accurately than claim more.

41 Significance and uniqueness

Sixteen problems, one sentence. That ratio is the paper’s claim to significance, and it deserves to be stated with care.

(1) One instrument, sixteen problems. The treatments of Parts III–VI are not sixteen applications of a vague theme but sixteen developments sharing one exact premise: *holonomy requires closed loops, and an interval has none*. Measurement and the four interactions, gauge invariance and the parameter sheet, the beginning and the hierarchy, the dark sector and the horizons, the discrete symmetries and the missing antiworld, the imprisoned quark and the immortal proton, time and its currencies, the landscape and the black hole — in the standard literature these are separate research programs with separate vocabularies, some of which have never cited one another. Here they are one anatomy, read sixteen times, and Table 17 is the exhibit. When a single structural sentence keeps landing in the load-bearing position of problems this far apart, the sentence is either a coincidence of language or a fact about the world; the falsifier table of §48 is the program’s commitment to finding out which.

(2) The explanations are structural, hence cheap. None of the sixteen treatments consumed a new field, a new symmetry, or a new continuous parameter. Each is the pair’s structure — premise (T), compactness against openness, and wherever an arrow is involved premise (D), the boundary law’s compulsory projection — doing work that the standard accounts assign to dynamics (confining potentials, collapse

Table 17: The master table: the sixteen problems and the anatomy’s answers. Mechanism column: C = the circle’s work, I = the interval’s, C+I = the pair jointly. Grades as in §47: D derived, DC derived-conditional, N named input, P postulated step in chain, F flagged.

#	Problem	Mechanism	Sharpest number	Grade	Dies by
1	Measurement	C+I: the write is the interval registering what the circle carried (Eq. (5))	Born measure at relaxation grade; F25 relic form	DC	large-scale statistics; interference revival
2	Four interactions	C: two keepers; I: one agent; the warp integrates	$v = 246.3$ GeV; lock at 3.849 TeV	D/DC	HL-LHC cluster null
3	Gauge + renormalization	C: unreadable pointer (Eq. (23)); I: one-way flow (Eq. (24))	anomaly sums exact (Eq. (25))	D	a running anomaly coefficient
4	Parameters	C+I: labels wearing addresses (Eq. (26))	137, 25/108, 246.3 vs measured	D/DC/N	any closed form off beyond audit
5	The beginning	I: the launch derived; entrance named open	$n_s = 0.9634$; $r = 0.0038$	DC	tensor null at SO/LiteBIRD floors
6	Naturalness	I: a depth, not a small number (e^{-K})	$K = 35 = LJ$, spent in four places	D	lock absent at staked sensitivity
7	Dark trio	I rolling once; C ringing still; both at rest	$8.1 \mu\text{eV} / 1.95$ GHz; $\Omega_\Lambda = 1 - 1/\pi$	DC/F	haloscope window closed; isocurvature
8	Three horizons	launch (I), classes (C), groove (C+I)	sameness at $10^{-5}/10^{-6}/\text{exact}$	D/DC	spatial variation of any constant
9	Discrete symmetry	C+I: three orientation reversals (Eq. (36))	$\delta_{\text{PMNS}} = 196.4^\circ$; $\theta \lesssim 10^{-10}$	D/DC	CPT violation; δ_{PMNS} off
10–11	Antimatter + excess	C: two senses; I: gated one-way toll	$\eta_B \approx 7 \times 10^{-10}$ vs 6.12×10^{-10}	D*/P	η_B incompatible with chain
12	Confinement + proton	C: closure in threes; a gauged class, made integral	$\tau_p > 2.4 \times 10^{34}$ yr guarded	D	free color; proton decay
13	Time	C: the tick; I: the arrow; seam: the rate	$d \ln t / dr = 2$; ledger 140.24	D/F	chronology broken by any clock
14	Energy, mass, entropy	C: tick’s worth; I: write count; shore: exchange	S_{BH} spends all three constants	D	a free write; an inverse write
15	Landscape	C+I: quantized dial, unique floor (conditional), no re-choice	one vacuum, forced (Eq. (51))	DC	any drawn constant
16	Black-hole information	C keeps; I prices; Page schedule	T_H , S_{BH} , turnover at Page time	DC	information loss confirmed

postulates, arrow-of-time stipulations, inflaton menus, axion zoos). Explanations that spend topology rather than parameters cannot be adjusted when they fail; that is their scientific value.

(3) Determinism, without a lottery. The three mechanisms of Part II — the quantized dial, the Morse-unique floor at the conditional grade §18 prints for it, the semigroup that cannot re-choose — run through every Part: the alphabet did not draw its chirality, the excess did not draw its sign, the Kaxion did not draw its angle, the vacuum did not draw its shares. The universe of this paper is not one lucky outcome among many; it is the playback of a groove. Symmetry breaking is symmetry reading — the paper’s second sentence, and its deepest.

42 The two families, delivered

Part I closed its diagnosis with a sorting: the sixteen problems fall into a family about *exactness* (what could make a quantity so protected that fifty years of instruments cannot budge it?) and a family about *one-wayness* (what could make a direction in which nothing returns, in a world of reversible equations?) — and the claim was that both families are what happens when a world with two kinds of direction is described in a language that has only one. The discussion’s first duty is to check that the treatments actually delivered along that split, because the diagnosis was a promissory note and Parts III–VI were the payment.

The exactness family, closed by the circle. Every exactness on the list came back as holonomy-class data, protected by Eq. (13)’s inverses and the integrality of winding: *CPT* (the total orientation, Problem 9), charge quantization and the anomaly sums (Problem 3), the proton’s double guard (Problem 12), the antiparticle’s perfect mirror (Problems 10–11), the sameness of the classes across the sky (Problem 8), the parameter sheet’s integer font (Problem 4), and the constants’ refusal to drift (Problem 15). In no case was the exactness enforced by a dynamical mechanism that could be adjusted; in every case it was the absence of anything continuous to adjust. That is the family’s one lesson, learned seven ways: *perfect protection is not strong dynamics; it is topology.*

The one-wayness family, closed by the interval. Every irreversibility on the list came back as semigroup transport, priced by Eq. (14)’s missing inverse: the measurement write (Problem 1), the renormalization flow (Problem 3), the descent and its hierarchy of addresses (Problems 2 and 6), the launch’s one traverse (Problem 5), the arrow and the age ledger (Problem 13), the write count and its toll (Problem 14), and the evaporation schedule (Problem 16). In no case was the arrow imported through an initial condition or a coarse-graining choice; in every case it was the composition law of the fiber the process lives on. The family’s one lesson: *irreversibility is not statistics; it is algebra.*

The four that needed both. The problems the century found hardest — measurement (1), the dark trio (7), time (13), and the black hole (16) — are precisely the four whose statement requires both fibers in one sentence: a coherence that is kept *and* a registration that is final; a coordinate that rolls *and* a coordinate that rings; a tick *and* an arrow; a register *and* a channel. On the one-language account each of these is a collision between exactness and one-wayness with no rule for how they share a world; on the two-fiber account each is simply a place where the anatomy’s two members meet — and the meeting has a grammar (the gearbox of §19) rather than a paradox. That the century’s hardest problems are exactly the two-fiber problems is, to this paper’s reading, the single strongest piece of internal evidence that the diagnosis was right.

43 The two white papers: history and anatomy

A note on the division of labor between this paper and its sibling. GG-W1-Symmetry (Arisaka, 2026, W1-Symmetry) is *diachronic*: it walks the century — Noether (1918) to Hopkins and Singer (2005) — and shows the conviction “symmetry causes conservation” loosening at seven historical steps, with the program placed at the arc’s end. The present paper is *synchronic*: it takes the structure that the arc arrives at — protection by topology rather than by symmetry — and dissects the geometry that implements it, one anatomy, six organs. The two are complementary readings of one claim: W1 argues that physics was already moving from symmetry to topology as the custodian of exactness; W2 exhibits the custodian’s anatomy and its books. A reader persuaded by neither alone might note where they interlock: the deepest step of W1’s ladder — the integer protected because integers have nowhere to move — is precisely the circle of this paper’s Part II, and W1’s capstone sentence — symmetry breaking as symmetry reading — is this paper’s §18, arrived at from the other direction.

44 How (D) sits with (A), (B), and (C)

Part II set out the program in four development steps (§12, Table 3), and this paper’s place among them should now be stated structurally, since the four are not four topics but four load-bearing stories.

(A) is the arena (A1–A4, §12.1): the constitution’s axioms, GGEP, and the six-dimensional bulk of Eq. (1) carrying the composite connection of Eq. (2), with the integer ledger of Eq. (3), anomaly freedom, and no free parameters. **(B) is the law** (A5–A7, §12.2): OGGEF declares observation a projection; GDOS gives the resulting open dynamics its generator, Eq. (5); GRIP = DGI + GFF + GSSB + GGA, Eq. (7), runs the cascade to the stratum’s attractor; and $U(1)_{Q_i}$ prices the record, Eq. (8). **(C) is the payout** (A8–A11, §12.3): quantum mechanics, the Standard Model, Λ CDM, and the origin of life and mind, each derived from (A) and (B) at declared grades — the codebook’s twenty-eight entries, the inventory’s π -locked shares, the cascade’s seventeen events. **(D) is the synthesis** (§12.4): the two white papers, of which this is the second — GG-W1-Symmetry reading the program *diachronically*, against the century of symmetry, and this paper reading it *synchronically*, against the sixteen problems. The two-fiber anatomy is (D)’s instrument: not a fifth ingredient, but the recognition that (A)’s two non-spatial directions are opposite in topological kind, and that (B)’s entire phenomenology and (C)’s entire payout are organized by that opposition.

The relations run in both directions, and both matter.

(D) needs the other three. Without (A) there is no pair to sort: the anatomy is a statement about a specific forced geometry, not a general aphorism about compactness, and if the bulk were otherwise the sentence would have nothing to be true of. Without (B) the interval’s semigroup would be a formal remark about composition rather than a physical arrow: it is OGGEF that makes the projection compulsory and GDOS that makes the one-wayness dynamical. And without (C) the anatomy would be an aesthetic claim with no numbers in it — every quantitative column of Table 17, from 137 to $8.1 \mu\text{eV}$ to 140.24, is a result of the applications, sorted by the anatomy but produced by (C).

The other three need (D) to be legible. The arena supplies the fibers; the law supplies the dynamics; the applications supply the numbers — and none of the three says, in its own voice, *which fiber is doing which job*. That is the anatomy’s office: it is the index of the whole program, and the reason a newcomer can now reach twenty-two papers through one sentence rather than through twenty-two introductions. The campaign recorded in Table 5 is the evidence that the index is real: it entered every paper through that paper’s own central topic, and required no value, grade, or theorem to change anywhere.

A closing observation about order. In the cohort’s own history the sequence was (A), then (B), then (C), and only then (D) — the anatomy was noticed last, after the applications had been built, which is the ordinary

way of such things: one sees the skeleton after the body is assembled. In the logic of the subject the order may well be reversed. A reader who accepts nothing but the anatomy — one hidden direction that must forget, one that cannot — has already accepted the census that forces most of (A), since (§16) a bulk with any other pairing cannot host a world that both is and becomes; and a reader who accepts (A) and the projection has (B) nearly for free. The program was built bottom-up and can be read top-down, and this paper is the top-down reading.

45 What is different from the standard accounts

Structural contrasts only; no polemic is intended, and the comparisons are with textbook framings rather than with any research program’s frontier.

- *Gauge theory* treats holonomy as a derived quantity of a postulated connection; here the split between where holonomy can live (S^1_θ) and where it cannot (I_r) is load-bearing, and the gauge sector’s observable content is read off it.
- *Thermodynamics* postulates the second law; here the first and second laws are the two fibers’ ledgers, and their famous tension is a division of labor between a group and a semigroup.
- *Quantum foundations* adds a measurement postulate to a unitary core; here the coherent half and the registering half are the two fibers, and a measurement is a read.
- *Baryogenesis model-building* assembles Sakharov’s conditions from imported parts; here the three conditions are three organs of one geometry, and the excess is computed with its open joints named.
- *Inflationary cosmology and axion phenomenology* scan menus (potentials; decay constants); here a census forbids the menus: one interval, one inflaton; one circle, one axion.
- *The cosmological constant problem* asks why the vacuum is small against a natural scale; here the vacuum’s scale is the descent’s depth squared, its share is a fiber-volume ratio, and the question becomes the (still open, honestly flagged) e-fold budget.

46 Where the objections are answered

Every synthesis of this scale attracts objections, and the strongest of them deserve more room than a Discussion can give. They are therefore collected in their own Part: Part X answers, at length, the objections a careful reader should raise — that the anatomy is a metaphor, that the interval is merely the renormalization group renamed, that compactness explaining quantization is textbook Kaluza–Klein, that deriving an arrow from a semigroup is circular, that the quantitative face is a patchwork of grades, and that a sentence explaining everything explains nothing — together with the questions a curious reader asks first. Nothing in this Part’s argument is held back from that one: the objections are stated in their sharpest form, and where the honest answer is “not yet,” Part X says so and names the work order.

47 The honest ledger

The paper’s claims are only as strong as their weakest named joints, so the joints are collected here in one place, exactly as the parent papers carry them.

- **Derived, unconditional** (within the cohort’s declared axioms): the anatomy itself; the fates of $C/CP/CPT$; the singlet rule; the proton’s guard, read as a gauged conservation law whose charge registration makes integral (integrality alone forbids nothing, §35.5); the exact slope $d \ln t / dr = 2$; the Hopf fractions; the seesaw arithmetic — the identity, not its identification with the measured vacuum density, which carries the uncomputed ζ_Λ ; the census.
- **Derived-conditional, conditions named:** n_s and r (the GDOS plateau-class derivation and the prompt-crossing lemma); $w = -1$ exactly (bulk rigidity, the KK spectral gap, flux freezing); the Born rule at relaxation level (the field-grade representation step is the one named analytic residue); the Kaxion’s patch-uniform angle (the pinning — killable by isocurvature); the determinism triad’s *unique* floor — the cascade is known to stop, and that it stops in one place is Frankel–Atiyah’s theorem on admissible strata and open elsewhere, the Wilson-line stratum first among the elsewheres (§18).
- **Named inputs and regulators:** the scalar amplitude A_s (the launch’s one declared input); the geometric phase assignment and the flavor-measurement regulator in the η_B chain; the $K/2$ exponent of the throughput, postulated.
- **Open integers and coefficients:** the cap loading $\Xi_{\text{cap}} = 43$ (benchmark; the discrete window 1.59–2.13 GHz); the drainage factor ζ_Λ (uncomputed; flagged home); and — listed here because Table 20 grades Problem 12 *reread* rather than *solved* — the field-theoretic proof of the mass gap, which the closure rule explains but does not supply (Jaffe and Witten, 2006).
- **Flagged, numerology discipline:** the $4K$ age compression and its doubled forms ($8K$ for the vacuum hierarchy and the de Sitter entropy) — one observation, three faces, whose would-be derivation is the queued e-fold budget campaign; the $e^{-K/3}$ warp candidate for the plateau edge.

Nothing above is a concession extracted by a critic; it is the cohort’s own register, reproduced because the synthesis would be worthless without it.

48 The ways to be wrong

The table has six rows, not sixteen, and the difference is worth stating rather than leaving to a reader who counts. Six consequences are exposed *directly*: a named channel, a named instrument, and an era, mostly within the decade. The other ten carry no instrument of their own, and their exposure is of a second kind — weaker, but not nothing. Every row of Table 17 is spent out of one ledger, $(M, N, L; J, K) = (1, 3, 5; 7, 35)$, and the comparisons in §49 span twelve orders of magnitude of experimental technique with no shared systematics. If the lock cluster is absent at 3.849 TeV, or the haloscope window closes empty, or the tensor ratio lands away from 0.0038, the integers do not survive — and the ten treatments that spend them do not survive either, whether or not anyone has built an instrument pointed at those treatments directly. That is the honest shape of the claim: six treatments can be killed on their own, and all sixteen can be killed together. The anatomy is a single sentence; the table is the part of its exposure that carries a date; and the program regards the size of the table as the measure of the sentence’s worth.

49 The numbers of this paper, on one page

Reproducibility is the cohort’s standard, so Table 19 collects every number this paper has quoted with its closed form, its value, and its measured comparison where one exists. Each was re-derived programmatically in the preparation of this paper; none is carried from memory.

Table 18: The consolidated falsifier table: the six consequences exposed on named instruments in named channels. The other ten treatments carry no instrument of their own and are exposed through the shared ledger, as §48 states. Each entry is registered in the cited parent paper; dates are the cohort’s decision-calendar estimates.

Consequence	Kill condition	Instrument / era
Discrete symmetry (Problem 9)	any CPT violation (particle–antiparticle mass split at any precision); δ_{PMNS} off 196.4° beyond errors	antihydrogen spectroscopy; DUNE / Hyper-K, late 2020s–30s
Antimatter (Problems 10–11)	measured η_B incompatible with the chain beyond its declared joints; sphaleron-era physics contradicting $\Delta B = 3n$, $B-L$ exact	CMB + BBN concordance; collider EW-sector tests
Confinement / proton (Problem 12)	observed proton decay violating the double guard; any fractional-charge or free-triality state	Hyper-Kamiokande; collider searches
Time (Problem 13)	measured z_{dec} off the atomic chain by $> 0.5\%$ (F7, observable-only); chronology inconsistent with slope 2 / kink 3/2	CMB spectroscopy; BAO + chronometers
Interactions (Problem 2)	KK lock cluster absent at 3.849 TeV with the predicted fingerprint; $\sin^2 \theta_W$, $\alpha^{-1}(0)$ closed forms failing at precision	HL-LHC, 2030s
Dark trio (Problem 7)	tensor r off 0.0038 in either direction; $n_s < 0.955$; axion-sector isocurvature detected; no line in 1.59–2.13 GHz at DFSZ depth, or a second light line in it; $w \neq -1$ or phantom crossing	Simons Observatory / LiteBIRD; IBS-CAPP / ADMX-EFR; Roman / DESI, 2030s

Table 19: The consolidated number audit. Grades as in §47; measured values from the Planck 2018 and PDG compilations via the parent papers. Nineteen rows, each giving the closed form, the value it produces and the measurement or reach it faces — from the lock scale at 3.849 TeV and $\alpha^{-1}(0) = 137.0$ down to the PMNS phase at 196.4° . Two rows carry their own warnings and are printed with them: the corridor switch $e^J = 1096.6$ is a topological marker with no observational counterpart, and the age ledger’s $4K \times 1.0017$ is flagged rather than claimed.

Quantity	Closed form	Value	Compared with
lock scale	$\frac{1}{2}M_{\text{Pl}}e^{-K}$	3.849 TeV	HL-LHC target
fine structure	$2^J + N^2$	137.0	137.036 (−0.03%)
weak angle	$L^2/(4N^3)$	0.23148	0.23122 (+0.11%)
EW vev	$M_{\text{lock}}(2/L)^N$	246.3 GeV	246.22 GeV
matter share	$1/\pi$	0.3183	0.3153 ± 0.0073
baryon share	$1/(2\pi^2)$	0.0507	0.0493
dark energy	$1 - 1/\pi$	0.6817	0.6847 ± 0.0073
crossover	$(\pi - 1)^{1/3} - 1$	0.289	$z_{\Lambda m} \sim 0.3$
tilt	$1 - 2/N^*, N^* = 52.6$	0.9620	0.9649 ± 0.0042
tensor ratio	$12/N^{*2}$	0.0043	< 0.036 ; SO/LiteBIRD reach
Kaxion mass	$\sqrt{\chi_{\text{QCD}}}/f_K$	8.1 μeV	haloscope window
Kaxion line	$m_K c^2/h$	1.95 GHz	IBS-CAPP / ADMX-EFR
twin split	ν_K/K	1.95 GHz/35 = 56 MHz	scale-free discriminator
seesaw scale	$M_{\text{lock}}^2/M_{\text{Pl,red}}$	6.1 meV	$\rho_\Lambda^{1/4} = 2.24 \text{ meV}$ ($\zeta_\Lambda^{1/4} = 0.37$)
baryon excess	$7.04 \cdot \frac{28}{79} \cdot 1.25 e^{-K/2}/g_*$	$\approx 7 \times 10^{-10}$	6.12×10^{-10} (+20%)
corridor switch	e^J	1096.6	<i>topological marker; no observational counterpart</i>
atomic decoupling	atomic chain	1091.1	1089.9 (+0.11%; §36.7)
age ledger	$\ln(t_0/t_{\text{Pl}})$	140.24	$= 4K \times 1.0017$ (flagged)
PMNS phase	$\pi + 2 \arcsin(1/7)$	196.4°	DUNE / Hyper-K

The table above is this paper’s own audit, and it is deliberately short — it carries only the numbers these sixteen treatments actually quoted. Figure 46 shows the cosmological half of that audit as the parent paper renders it: the fractional deviation of every observable carrying an empirical comparison, with the precision bands drawn (Arisaka, 2026, A10-Cosmos). It is included here because a table of agreements is easy to read charitably and a deviation plot is not: the entries that miss are as visible as the entries that hit, and two of them — the late-time H_0 and the baryon asymmetry — miss by amounts this paper names rather than absorbs.

Three reading notes. *First*, the left column’s grammar is uniform: integers and π ’s in the closed forms (the circle), exponentials of K in the scales (the interval) — the table is the gearbox of Part II, printed. *Second*, the comparisons span twelve orders of magnitude of experimental technique, from CMB polarimetry to haloscope cavities to collider clusters, with no shared systematics: the cross-exposure is deliberate, and a failure anywhere impeaches the ledger everywhere. *Third*, the table contains no entry with a tunable parameter behind it: every value is either an arithmetic of (1, 3, 5; 7, 35), a geometric measure, or a declared input named in §47 — which is why the table is short, and why it is dangerous.

50 Sixteen problems, sixteen dispositions

A final consolidation, in the discipline’s own severe vocabulary: for each of the sixteen, what exactly did the anatomy *do*? Table 20 is that consolidation; the verbs are defined below it and chosen deliberately, because the differences between them are the paper’s honesty.

Table 20: Sixteen problems, sixteen dispositions. What the anatomy actually did to each, in one verb, with the Part that did it. The verbs are defined immediately below; no two rows claim the same thing, and several claim conspicuously less than a partisan would.

#	Problem	Disposition	Where
1	measurement	dissolved: a measurement is a read; Born at relaxation grade	Part III
2	four interactions	solved by sorting: two keepers, one agent, one integrator	Part III
3	gauge + renormalization	re-founded: unreadability and one-way motion, derived	Part III
4	parameter count	repriced to a codebook: 6 + 14 + 8, graded in public	Part III
5	the beginning	transformed: launch derived; entrance a named open item	Part IV
6	naturalness	dissolved: a depth, not a fine-tuning	Part IV
7	dark trio	identified: the two fibers in the sky; scale flagged	Part IV
8	three horizons	solved in three parts: launch, classes, groove	Part IV
9	discrete symmetry	solved: orientations; fates by fiber; strong CP dissolved	Part V
10–11	antimatter + excess	mirror solved; excess computed, joints named (+20%)	Part V
12	confinement + proton	reread: closure rule; guard exact; formal proof open	Part V
13	time	solved at the root: tick, arrow, exact chronology	Part VI
14	energy, mass, entropy	defined: tick’s worth, class’s address, write count	Part VI
15	landscape	unemployed: a conditional floor; anthropic residue named	Part VI
16	black-hole information	dissolved: a billing error, on the Page schedule	Part VI

Solved means a derivation replaced a postulate. *Dissolved* means the question’s presupposition was located

Twenty-Two Observables, Three Declared Inputs: the Audit

A10-Cosmos parameter-audit Dev plot (violet diamonds: epoch-calibrated inventory)

Inner thick bar: $\sigma_{\text{obs}}/|\text{obs}|$. Outer thin bar: $\sqrt{\sigma_{\text{obs}}^2 + \sigma_{\text{th}}^2}/|\text{obs}|$. Filled markers: predictions. Open: anchored.

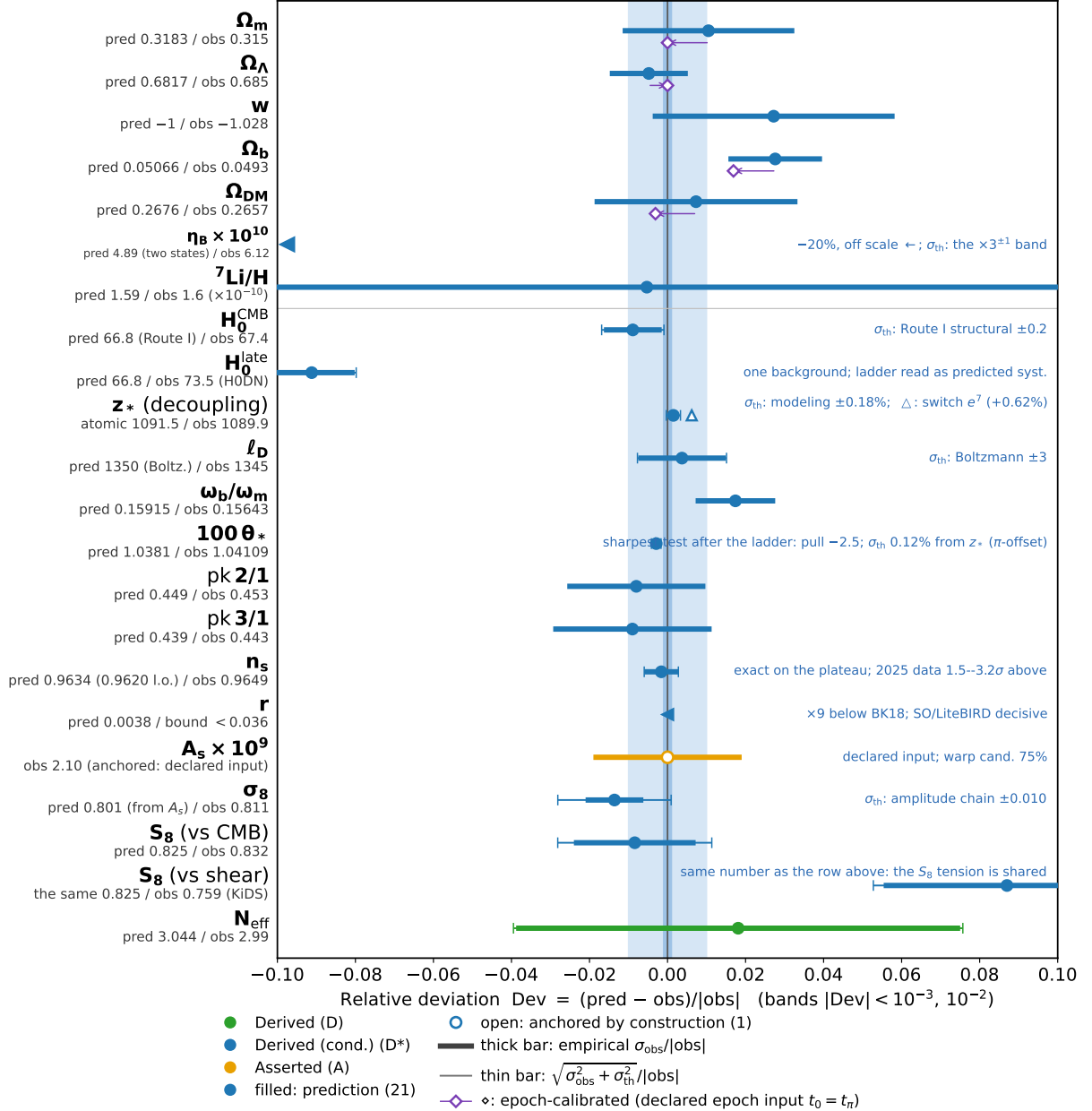


Figure 46: The cosmological audit, in one chart (reproduced from Arisaka, 2026, A10-Cosmos). The fractional deviation (pred - obs)/|obs| for the twenty-two observables carrying an empirical comparison — eighteen independent predictions (filled), four anchored by construction (open) — with nested precision bands at |Dev| < 10⁻³ and 10⁻². Two entries earn their place by missing. The late-time H_0 row sits low against the local-ladder value, which is the corridor's exposure rather than a free parameter's failure; and the η_B row sits 20% off in its band, carrying the one postulated exponent of the toll (Problem 11). The z_* row is the two-quantity discipline drawn: the framework's atomic-chain decoupling prediction is scored against the measured value, with the corridor switch e^7 annotated separately as a topological marker, never conflated with it. Nothing in the chart is a fit; the residuals are what a zero-parameter framework has to live with.

and removed — there was never a fine-tuned number, only an address; never a collapse, only a write; never a loss, only a ledger. *Re-founded* and *reread* mean the established mathematics was kept whole and given a referent. *Repriced* and *transformed* mean the problem became a different, sharper question that remains open — and the flagged register exists precisely so that repricing is never mistaken for solving. *Computed, joints named* means a number was produced with its open steps declared. *Identified* and *unemployed* speak for themselves. No row claims more than its grade in Table 17; several claim conspicuously less than a partisan would — which is the register the cohort intends to be read in.

51 The decision calendar

The falsifier table of §48 has a time axis, and it is short. Consolidating the parent papers’ calendars: *now through 2028* — haloscope coverage of the low edge of the Kaxion window begins; DUNE and Hyper-Kamiokande commissioning toward δ_{PMNS} ; antihydrogen precision advances. *2028–2032* — the tensor programs (LiteBIRD launch window; the Simons Observatory’s enhanced surveys) bracket $r = 0.0038$ from both sides; the HL-LHC integrated-luminosity curve crosses the staked sensitivity for the 3.849 TeV cluster’s primary channel; full-window haloscope coverage with a count-aware analysis. *2032 and beyond* — Hyper-Kamiokande’s proton-decay reach passes the guard-relevant channels; next-generation $0\nu\beta\beta$ reaches the band that arbitrates the driver’s Majorana prerequisite; Roman and DESI close the $w = -1$ error budget below the phantom-crossing ambiguity. By roughly a decade from this writing, every row of Table 18 will have been visited by at least one instrument. The paper’s sixteen answers were assembled from results already in hand; its wager is that they remain standing when the calendar has run — and the cohort’s practice, recorded in every parent paper, is to publish the verdicts either way.

52 Open problems and queued campaigns

Four items, inherited from the cohort’s ledger, would most sharpen this paper if closed: (1) *the e-fold budget* — deriving T_0 through the descent with no dial, converting the $4K/8K$ family from flagged to theorem; (2) *the relic quantification* (A, γ) of the Born-relaxation signature F25 at the largest scales; (3) *the field-grade representation step* — the Born chain’s last analytic residue; (4) *the cap integer* Ξ_{cap} — one integer between the Kaxion’s benchmark and its theorem. Each is a campaign, not a gap: named, scoped, and owned.

53 Part VII in one paragraph, and what comes next

The consolidation is done. Sixteen problems sit in one table with sixteen separately stated dispositions and sixteen grades; the weak joints are collected in one ledger rather than distributed through the argument where they would be easy to miss; the numbers are in one audit with their closed forms beside them; and the ways to be wrong are in one table with instruments and dates attached. Four campaigns are named as campaigns, not gaps. Where this reading differs from the programs it will be compared with, the difference is structural and is stated as such.

That is the apparatus. Part VIII says the whole thing once more in plain language, for the reader who wants the answers and not the machinery — and then says what the author actually thinks it means.

Part VIII

Conclusions

The Circle Remembers; the Interval Forgets

54 What has been established

This paper began with a list — sixteen questions, median age seventy years, that the best instruments and the ablest people have sharpened for two generations and closed almost never — and with a diagnosis: the list is long not because the questions are many but because one structural fact is missing from all of them. The world has two kinds of direction, and physics has been describing it in a language with one.

Part II supplied the fact. The six-dimensional bulk of GG-Theory carries, over every point of space, a closed circle and an open interval; holonomy requires closed loops, and an interval has none; so one hidden direction is pure memory — quantized, protected, reversible — and the other, once the boundary law’s compulsory projection is laid along it, pure act — one-way, priced, final. Two premises, stated apart in §13 and kept apart since: the topology says which fiber can hold a record, and the projection says why the other one’s acts do not come back. *The circle remembers; the interval forgets.* Parts III–VI then spent that sentence on the sixteen, one by one, at essay length, with the equations displayed and their parameters defined: the exactness problems taken by the circle, the one-wayness problems taken by the interval, and the four that have resisted longest — measurement, the dark sector, time, the black hole — taken by the pair meeting, because a meeting is what each of them always was. *Taken* is the right verb and not a modest one: Table 20 grades nine of the sixteen with verbs that are not “solved,” and those grades stand.

What was established, precisely: every claim carried here is a cohort result, cited at its parent’s grade, with the open joints named in place (§47) and the kill conditions collected, dated, in one table (§48). The paper added no axiom, no field, and no parameter; its contribution is the alignment — and the observation that the alignment is not optional: one fiber of each kind is the minimum a world needs in order to both be and become. Whether the alignment is a fact about nature or only about our description is not decided in these pages; it is decided by the instruments of the coming decade, and the paper has done everything a paper can to make their verdict unambiguous.

55 A note on teaching

If the falsifier table survives its decade, the pedagogical consequence deserves to be anticipated, because it is larger than a new chapter. The two-fiber anatomy is teachable *first* — before Lagrangians, before groups, almost before calculus: one direction that must forget, one that cannot; the circle keeps promises, the interval makes events; and the sixteen problems then arrive as one lecture each, with the exact statements attached later as the student’s mathematics matures. Much of what the present curriculum presents as brute — why quantum numbers never drift while couplings run, why the second law never reverses while the first never fails, why measurement is one-way, why antimatter mirrors matter exactly and yet lost — becomes, in this order of teaching, the *expected* behavior of a two-fiber world, with the surprise relocated to where it belongs: that nature audited the picture and, so far, signed. The conditional is essential and repeated: curricula follow experiment, not elegance, and Part VII’s table is the tribunal. But a physics that can be taught from one

sentence outward owes its students that sentence early — and this white paper is, among its other purposes, a first draft of that course.

56 What has changed since W1, and what has not

Six months separate the first white paper’s assembly from this one, and the interval (the word is now unavoidable) saw the campaign deploy the anatomy across the entire cohort. It is worth recording, as a conclusion in its own right, what that deployment changed and what it conspicuously did not. *What changed*: the cohort acquired an index — every paper now names which fiber does which job in its central result; three portraits (electron, proton, Kaxion) and one trio (rolling, ringing, rest) were completed; the leptogenesis chain was assembled end to end with its joints named; the treatment of time was expanded from a section to a quantitative chronology; and this paper became possible — a single document from which a newcomer can reach the whole program through one sentence. *What did not change*: a single number. No value was retuned, no grade promoted, no theorem’s conditions relaxed anywhere in the twenty-two papers the campaign touched — the deployment was an audit, and the audit passed. A skeptic should weigh that fact at full strength, because it is unusual: organizing languages in physics ordinarily earn their keep by suggesting modifications; this one earned its keep by *failing to require any*. The anatomy fit the cohort the way a description fits a thing that was already there — which is either the strongest thing that can be said for it short of experiment, or an elaborate selection effect; and Part VII’s table exists because the difference is not for us to adjudicate from the armchair.

57 The sixteen answers, in sixteen sentences

For the reader who asked only for the conclusions — one sentence per problem, in the order of Part I:

1. A measurement is the interval writing what the circle carried: the coherent half of quantum mechanics is transport with inverses, the registering half is transport without them, and the century’s “cut” is not a place but the meeting of the two.
2. The four interactions are one bulk connection read on different structures: two forces keep the circle’s books, the weak force is the interval’s agent — which is why it alone is chiral, broken, and identity-changing — and gravity is the descent’s own bookkeeping, which is why it will not quantize like the rest.
3. Gauge invariance is the circle’s unreadability and renormalization is one-way motion along the interval: the two principles that carried all of field theory were the two fibers, used for a century without being named.
4. The parameter sheet is a codebook, not a list of dials: every entry is a holonomy-class label wearing a descent address, and the audit is public — six derived, fourteen conditional, eight still owed.
5. The Big Bang is a launch, not a wall: the plateau class is forced, the roll happens once, its two fingerprints (n_s, r) are staked, and what remains open is an entrance with a work order, not a mystery with a veil.
6. Nothing about the weak scale is small; something is deep — thirty-five e-folds of descent, an integer spent in four places, and the forty-year anxiety retires without a single cancellation. Of the two ratios that anxiety names, the weak-scale half retires outright; the vacuum-energy half retires to within an uncomputed drainage factor of $\zeta_\Lambda^{1/4} = 0.37$, which is a smaller claim and is made as one.

7. Inflation is the interval's coordinate rolling once, dark matter is the circle's coordinate ringing still at $8.1 \mu\text{eV}$, and dark energy is both at rest: the dark sector is the two fibers, seen in the sky.
8. Distant strangers agree because the launch shared their conditions, the classes cannot vary, and the groove has one floor on the one condition Part II names: three horizons, three mechanisms, no lottery.
9. C , P , and T are the geometry's three orientation choices; each single sense can be fixed by a structure, the joint reversal cannot — so CPT is exact and the others fail exactly where the alphabet and the runtime say.
10. Antimatter exists because a circle has two winding senses — the same class, read backwards, which is why the mirror is perfect.
11. The excess of matter is a paid toll: a chiral tape read once through a gated one-way door at $e^{-K/2}$, delivering 5.9×10^{-10} against a measured 6.1×10^{-10} , joints named.
12. Quarks confine because the boundary registers only closed color books, and the proton persists because baryon number is a gauged holonomy class with no $\Delta B = 1$ aperture — the two facts every atom banks on, reread as one registration rule.
13. Time's tick is the circle's return and time's arrow is the interval's one-way reading, with the chronology exact: $d \ln t / dr = 2$, and an age ledger closing at 140.24.
14. Energy is what a tick is worth, mass is the address a class wears, entropy is what the arrow has read — three household words, finally with definitions, and one formula (S_{BH}) that spends all three fibers' constants at once.
15. The multiverse is not refuted but unemployed: the constants it was hired to explain are forced — a quantized dial, a floor whose uniqueness is conditional and named, a semigroup that cannot re-choose — and a lottery with one ticket needs no drum.
16. The black hole's information was never lost, only billed to the wrong book: the circle keeps what the hole must return, the interval prices the return, and the Page curve is the reconciliation schedule.

58 The oldest dispute in physics, and what the pair says about it

A conclusion for the long view, in three steps — each a philosophical claim, and each anchored to an equation rather than to a mood.

Being and becoming were never rivals. The oldest dispute in natural philosophy — older than physics itself — is whether the world fundamentally *is* (Parmenides: what is real does not change) or fundamentally *becomes* (Heraclitus: what is real is change). Twenty-five centuries later the dispute is still legible in the discipline's deepest tension: exact conservation against irreversible flow, unitary evolution against the completed measurement, the frozen laws against the running history. The two counterfactual worlds of Part II are the two positions taken purely: the all-circle world *is* and never becomes — perfect conservation, no event ever — and the all-interval world *becomes* and never is — perpetual change, nothing to change. Both are sterile, and for exact reasons: Eq. (13) alone permits no record; Eq. (14) alone protects no thing. A world requires one of each, geared together — and that is not a compromise between the two ancient positions but the discovery that they were always the two fibers of one geometry, each correct about its own direction. The dispute does not have a winner. It has an anatomy.

Why the world is comprehensible at all. Einstein called it the most incomprehensible thing about the universe — that it is comprehensible — and Wigner gave the puzzle its sharpest form: why should mathematics, invented by primates for counting, fit nature to twelve digits? The anatomy’s answer has been implicit since Part II and deserves to be said plainly. Science requires two things of a world: that something never change (else no law could be written down, no experiment repeated, no memory trusted) and that something always happen (else there would be nothing to explain and no one to explain it). These are exactly the two fibers. The circle underwrites the possibility of *knowledge* — protected classes are why the electron a student measures tomorrow is the electron in tonight’s textbook — and the interval underwrites the possibility of *learning* — one-way writes are why evidence accumulates instead of evaporating. A one-fiber world of either kind would contain no science, not because science would be hard there but because its preconditions would be absent. Comprehensibility is not a lucky property of our universe; on this reading it is a structural consequence of the same pair that makes the universe habitable — and the mathematics fits because the mathematics (a group, a semigroup) *is* the structure, written small.

A forced structure is not a finished story. The determinism of this paper is total at the level of structure — which layers exist, which constants hold, which vacuum is the floor, each at the grade Part II prints and one of them conditionally (§18) — and deliberately silent at the level of history. The groove fixes the kind of world; it does not compose the weather, the biosphere, or the sentence the reader will think next. Those live in the combinatorial openness that a fixed alphabet permits — as a language with a finite grammar permits unbounded literature. The anatomy therefore delivers a rarer thing than either fatalism or chance: a world whose *reliability* is guaranteed (the circle cannot break its promises) and whose *future* is genuinely unwritten at every scale where composition matters (the interval writes only once, and has not yet written tomorrow). Physics has long been suspected of leaving no room for novelty; the two-fiber reading locates the room exactly — everything above the alphabet, which is nearly everything — and prices what was actually forced: the stage, the letters, and the guarantee that the letters keep. It is difficult to imagine a more generous constitution: everything needed for a world is fixed, and everything interesting in one is free.

59 A personal closing

The question that made me a physicist arrived in high school: nature seemed too beautiful, too well arranged for us to be here, for the arrangement to be an accident — and I wanted to know why. I have carried that question through five decades on the experimental front line — through detectors for proton decay and neutrinos, through the precision instruments of particle astrophysics — and through every costume the question wore: why does symmetry break the same way everywhere; why did matter win; why does the proton keep; why does time run; why is the dark sector what it is; why these constants and no dial anywhere to set them. I did not expect, at the end, that the answers would share a single sentence. The work collected here says they do: *the universe has one direction that must forget and one that cannot* — and everything I spent my life puzzling over is the interplay of those two. The tape and the read head. The groove and the playback. The being and the becoming.

The circle remembers: the charges, the phases, the alphabet, the books — every promise the universe has ever kept, it keeps there. The interval forgets: every scale visited once, every choice made final, every record priced and paid — and precisely because it forgets, something can happen at all. Between them they need no third thing, and the constitution supplies no third thing. Sixteen problems, one anatomy: not because I went looking for a slogan, but because — as the campaign that built this paper taught me — the alignment was already in the physics, waiting to be read. Not contingent. Not lucky. Not designed. Forced.

I am aware of how large these claims sound, and I have tried to make the paper’s honesty as prominent as its

ambition: the grades are stated in place, the open items are named as work orders, and Part VII's table lists the measurements on which each answer dies. If the instruments of this decade — the tensor telescopes, the haloscopes, the proton watchers, the colliders — return the numbers staked there, then I believe this sentence will deserve to be taught first, before the forces, before the fields: *the circle remembers; the interval forgets; and the world is what that sounds like, played once*. If they return other numbers, the table says exactly what dies, and I will publish the verdicts either way — that has been the cohort's practice at every step, and it is the only practice worthy of the question. Either way, we will have learned something that cannot be unlearned — which is all I ever asked of physics, and more than I dared hope it would give back. There remains only gratitude, and an invitation.

The gratitude is easy to name. To the experimental collaborations whose patience built the instruments this paper stakes itself on — the haloscope halls, the neutrino caverns, the polarization telescopes, the collider — and to the tradition of physicists, many quoted in Part I, who kept these sixteen questions alive through decades when working on them was unfashionable: this paper is a reading of a house that others built, and it knows it. And to the reader who has come this far: a synthesis is only ever completed by the person who checks it, and you have my thanks for the hours.

The invitation is the closing I most want to write. If you are a student, the next decade of this program belongs to you more than to me: the falsifier table is a to-do list, the flagged family is a thesis waiting for its author, the entrance is the best open problem I know, and the e-fold budget campaign — which would turn the deepest flagged number in the cohort into a theorem — is specified to the point where someone with fresh eyes and a long morning could begin. Take the sentence, try to break it, and publish what you find either way; the paper is built so that both outcomes are progress. I have spent fifty years learning that the universe rewards exactly this kind of stubbornness — and that it is far more beautiful, and far more orderly, than we had any right to expect.

The universe keeps one direction that cannot forget and one that cannot remember, and out of their marriage comes everything: atoms and their patience, stars and their spending, records and their keepers, physicists and their questions. I find I am no longer troubled by the question that started me in high school. The arrangement is not an accident, and we were not lucky to be here. The tape was pressed; the head was set; and the playback — fourteen billion years of it, so far — has been, among all its other works, the slow manufacture of readers. This paper is for them.

Katsushi Arisaka

Los Angeles, August 2026

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All scientific concepts (especially the foundation of the GG-Constitution, GGEP/GG-6/BI-6, and OGGE/GDOS/Gi-4/Qi-4 Pillars), theoretical judgments, physical interpretations, and any remaining errors are the sole responsibility of the author.

One acknowledgment is particular to this paper. A synthesis owes a debt of a kind an original paper does not: everything carried here was proved somewhere else first, and the sixteen treatments stand or fall on work done in the cohort papers rather than in these pages. Where a result is quoted at a grade below *derived*, that grade was set by the parent paper and not softened here; where a step is still open — the field-grade representation step, the entrance corridor, the drainage factor ζ_A , the postulated $K/2$ exponent — it is named in place rather than carried quietly. The reader who wants to attack this paper should attack those joints, and the author would count that a service.

Finally, a word to the readers this paper was written for and who have not yet been thanked because they have not yet read it: the students who will check these claims, find the errors, and either repair the framework or retire it. The sixteen problems have outlived every physicist who has so far worked on them. If the reading offered here is right, some of them will not outlive the next generation of instruments; if it is wrong, the instruments will say so just as clearly, and that is the arrangement under which all of this is worth doing.

What follows

What follows is not afterthought but apparatus. Part IX derives from scratch what Parts III–VI could only quote — nine topics, each in four steps, beginning with a full textbook treatment of the standard material before a word is said about anything new, with the problems worked and the solutions given. Part X argues with the reader: one hundred and seventeen objections, the first twenty-two from someone with no physics training and the rest from specialists, several conceded outright. Part XI says whose work every result here belongs to, what it cost the field, and where this paper reads it differently.

Part IX

Technical Appendices

A Graduate Course in the Two-Fiber Anatomy — From-Scratch Derivations of the Machinery behind the Sixteen Problems, Each in Four Steps

The body of this paper carried its results at their parents' grades and kept the derivations in the cohort papers where they belong. The present appendices supply what a student needs in order to check them, and taken together they are intended to be read as a *graduate course in the two-fiber anatomy*, addressed to the incoming physics graduate student who will carry the program forward — or break it.

They are organized in two groups. The *reference* appendices (§61–§62) tabulate the abbreviations and symbols used throughout, and serve as the reader's quick lookup. The *constructive* appendices are the course proper: a self-contained sequence that follows the order of Parts III–VI — open quantum systems and the measurement write; gauge invariance and the renormalization group; the parameter codebook; the launch and the descent; the dark sector; the discrete symmetries and the matter excess; confinement and the proton; and time, entropy, and horizon thermodynamics — preceded by the appendix on holonomy itself, which is the instrument every later chapter uses.

Each constructive appendix is written in *four steps*, and the four are the same every time:

1. **Step 1 — the standard treatment.** A from-scratch derivation of the established result, in the form a graduate student meets it in a textbook, carried through with no skipped manipulations and closed by a worked example. Nothing in Step 1 is this program's: it is the discipline's own material, presented so that the reader has something exact to hold before anything new is asked of them.
2. **Step 2 — what remains unexplained.** A frank statement of what the standard treatment *assumes but cannot explain* — the inputs it must take from experiment, the postulates it must adopt, and the structural questions it leaves open. Each Step 2 ends by naming which of the sixteen problems of Part I lives in that gap, so the reader can see the ledger being drawn.
3. **Step 3 — the two-fiber resolution.** The same material reread on the anatomy: which quantity is circle-side and protected, which is interval-side and priced, and what changes when the sorting is applied. Grades are stated in place, exactly as in the body; where the resolution is conditional or flagged, Step 3 says so.
4. **Step 4 — problems and worked solutions.** Exercises with complete solutions, each worked in short numbered steps and closed by a *physics intuition* remark. They are the point of the course: a reader who works them has checked the chapter rather than read it.

Two conventions. Equations already displayed in the body are cited rather than repeated, so the appendices and the body form one document rather than two. And nothing in these appendices is load-bearing for the body's claims: they teach the machinery, they do not extend it. A reader who wants the argument should read Parts I–VIII; a reader who wants to *use* the argument should work these chapters.

60 Recommended textbooks and key papers

The course below is self-contained, but no appendix can replace a term with a good book. What follows is the reading the author would put in front of an incoming graduate student, grouped by the appendix it

serves. Where a single paper changed the subject, it is named alongside the textbook, because reading the original is usually faster than reading a summary of it.

Geometry, bundles, and holonomy (Appendix 63). [Nakahara \(2003\)](#) is the standard bridge from a physicist’s calculus to fiber bundles: Ch. 9–10 contain everything this course uses. [Misner et al. \(1973\)](#), Ch. 8 and 11, teaches parallel transport with the pictures drawn, and is still unmatched for intuition. [Wald \(1984\)](#) gives the same material with mathematical care and carries the horizon theory of Appendix 71. The one indispensable paper is [Wu and Yang \(1975\)](#): the statement that the holonomies *are* the gauge field, which is the sentence this whole paper turns on. [Dirac \(1931\)](#) is worth reading in the original for the first argument that a physical quantity must be an integer.

Quantum mechanics and open systems (Appendix 64). [Sakurai and Napolitano \(2020\)](#) for the formalism at graduate level; [Nielsen and Chuang \(2000\)](#), Ch. 2 and 8, for density matrices, Kraus operators, and quantum channels — the cleanest modern treatment of the machinery Step 1 derives; [Breuer and Petruccione \(2002\)](#), Ch. 3, for the Lindblad theorem and decoherence models done at length. The papers to read are [Born \(1926\)](#) (two pages, one footnote, one rule), [Einstein et al. \(1935\)](#) and [Bell \(1964\)](#) as a pair, and [Zurek \(2003\)](#) for the decoherence program in its author’s own words.

Gauge theory and the renormalization group (Appendix 65). [Peskin and Schroeder \(1995\)](#) is the default first course; Ch. 15–17 cover non-abelian gauge theory, the renormalization group, and asymptotic freedom. [Srednicki \(2007\)](#) is more careful about anomalies (Ch. 72–77), and [Weinberg \(1995\)](#) is the reference for what a symmetry of an action does and does not buy. [Zee \(2010\)](#) is the book to read first if the others feel airless. Original papers: [Yang and Mills \(1954\)](#), [Weyl \(1929\)](#), [Wilson and Kogut \(1974\)](#), [Gross and Wilczek \(1973\)](#) and [Politzer \(1973\)](#), and [Elitzur \(1975\)](#) — the last a single page that settles what “breaking a gauge symmetry” can mean.

The Standard Model and its parameters (Appendix 66). [Georgi \(1999\)](#) for the group theory one actually needs; [Peskin and Schroeder \(1995\)](#), Ch. 20, for electroweak symmetry breaking; [Particle Data Group \(2024\)](#) as the standing reference for every measured value, its scheme, and its scale — a student should learn to read the Review of Particle Physics before trusting any quoted number, including this paper’s. [Cahn \(1996\)](#) is the essay to read on what the parameters *do*.

Cosmology (Appendices 67 and 68). [Baumann \(2022\)](#) is the best modern course and is pitched exactly at this appendix’s level; [Dodelson and Schmidt \(2020\)](#) for perturbations and the CMB; [Weinberg \(2008\)](#) when precision matters; [Kolb and Turner \(1990\)](#) remains the reference for relic abundances and the thermal history. Papers: [Guth \(1981\)](#), [Linde \(1982\)](#), [Starobinsky \(1980\)](#) for inflation; [Peccei and Quinn \(1977\)](#), [Weinberg \(1978\)](#), [Wilczek \(1978\)](#), and [Preskill, Wise, and Wilczek \(1983\)](#) for the axion; [Planck Collaboration \(2020\)](#) for the measured sky.

Discrete symmetries and baryogenesis (Appendix 69). [Weinberg \(1995\)](#), Ch. 2 and 5, for the discrete operators and the *CPT* theorem; [Peskin and Schroeder \(1995\)](#), Ch. 3, for their action on Dirac fields. Papers: [Lee and Yang \(1956\)](#) and [Wu et al. \(1957\)](#) as a pair, [Christenson et al. \(1964\)](#), [Kobayashi and Maskawa \(1973\)](#), [Sakharov \(1967\)](#), [Kuzmin et al. \(1985\)](#), and [Fukugita and Yanagida \(1986\)](#).

Confinement and the proton (Appendix 70). [Peskin and Schroeder \(1995\)](#), Ch. 17, for asymptotic freedom and the infrared; [Wilson \(1974\)](#) for the confinement criterion in the original; [Gell-Mann \(1964\)](#) and

[Greenberg \(1964\)](#) for how quarks and color arrived; [Jaffe and Witten \(2006\)](#) for the formal status of what remains unproven.

Time, entropy, and horizons (Appendix 71). [Wald \(1984\)](#), Ch. 12, for horizons and the area theorem; [Landauer \(1961\)](#) for the toll; [Bekenstein \(1973\)](#), [Hawking \(1975\)](#), [Hawking \(1976\)](#), and [Page \(1993\)](#) in the original — four short papers that between them define the subject. [Penrose \(1979\)](#) is the essay on why the early universe was special, and remains the sharpest statement of the arrow’s real difficulty.

And, for the program itself. The cohort papers named in Part II’s four steps: [Arisaka \(2026, A1-Constitution\)](#) for the axioms, [Arisaka \(2026, A2-GG6\)](#) for the bulk and the ledger, [Arisaka \(2026, A5-GDOS\)](#) for the boundary law, [Arisaka \(2026, A6-GRIP\)](#) for the engine, and then the application paper matching the reader’s own field. [Arisaka \(2026, W1-Symmetry\)](#) is this paper’s sibling and the better entry point for a reader who prefers history to structure.

61 Summary of abbreviations

Table 21: Summary of abbreviations used in this paper, each with its expansion and the place it is used. The first block is the program’s own apparatus, in the order of the four steps: GG-Theory and the two equivalence principles, GDOS and the GRIP engine with its four moves DGI, GFF, GSSB and GGA, the two GRIP regimes, and the parsimony clause MSMF. The remainder runs from the cohort’s own structures to the standard abbreviations of the field — BI-6, Hopkins–Singer, Qi-4, RG, CMB, EDM and KMS. Where an entry has an equation of its own, the equation is named, so the table doubles as an index into the paper’s numbered results.

Abbreviation	Expansion, and where it is used
GG-Theory	the program: geometry–gauge theory on the six-dimensional bulk (Part II)
GGEF	geometry–gauge equivalence principle (AX-2): gravity and the gauge forces as one composite connection (Step A)
OGGEF	open GGEF (AX-3): observation is a projection that marginalizes the fiber coordinates (Step B)
GDOS	geometric dynamics of open systems: the master equation Eq. (5) and its theorems (Step B)
GRIP	the runtime engine, DGI + GFF + GSSB + GGA, Eq. (7) (Step B)
DGI	Dynamical Gauge Invariance: the cascade’s opening move — every gauge equivalence intact, nothing yet committed
GFF	geometric free-energy functional: the Lyapunov landscape the cascade descends — a Lyapunov function by Conley’s theorem, the relative entropy by Lindblad–Spohn, a moment-map component on an admissible stratum, the dilatation charge on the family stratum (§18)
GSSB	geometric spontaneous symmetry breaking: the selection step
GA / GGA	geometric attractor / ground geometric attractor: way station and deepest floor — unique on the condition §18 names
GRIP-In	the within-layer regime — the circle’s stroke, closed-loop relaxation on a fixed landscape

continued on next page

Table 21 continued

Abbreviation	Expansion, and where it is used
GRIP-Out	the between-layer regime — the interval’s stroke, the one-way reorganization of the landscape
MSMF	minimal structure, maximal function (AX-4): the parsimony clause that forbids convenience ingredients
Green–Schwarz	Green–Schwarz: the anomaly-cancellation mechanism, in its six-dimensional non-supersymmetric instance
BI-6	the modified Bianchi identity of the six-force bulk (A3)
Hopkins–Singer	Hopkins–Singer: differential-cohomology quantization, the far end of W1’s ladder
Qi-4	the four information pillars of A7
RG	renormalization group: the flow along the interval, Eq. (24)
CMB	cosmic microwave background
EDM	electric dipole moment (the neutron’s, in the strong- CP audit)
KMS	Kubo–Martin–Schwinger: the thermal-equilibrium condition at the shore (Problem 14)

62 Glossary of key symbols

Table 22: Glossary of key symbols, with meanings and first use. The geometry comes first: the six-dimensional bulk $\mathcal{M}_6$ and its two non-spatial factors, the scale interval I_r with coordinate $r = \ln(E_{\text{GUT}}/\mu)$ on $[0, K]$ and the phase circle S_θ^1 with coordinate θ . Then the integer ledger $(M, N, L; J, K) = (1, 3, 5; 7, 35)$ and what each entry counts: $K = 35$ e-folds of descent, $J = 7$ chiral steps, $N = 3$ the color triplicity, $L = 5$ the rank structure. The rest names the quantities the sixteen problems turn on, from the Wilson loop and circle transport through the cap loading Ξ_{cap} , the baryon-to-photon ratio, the QCD vacuum angle and the Arisaka constant, to the Bekenstein–Hawking entropy and the drainage factor ζ_Λ — named, bounded, and uncomputed.

Symbol	Meaning, and first use
N	The OGN-5 ledger’s second entry, $N = 3$. Every ledger identity is written with it
N_c	Color triplicity, the three colors of $\text{SU}(3)_C$ — what that entry counts
N_g	The generation (family) count, 3. <i>Not</i> a ledger entry; fixed by GG-P2-N3
N_f	The quark-flavor count of a beta function, $N_f = 2N_g = 6$ at high scale
$\mathcal{M}_6$	the six-dimensional bulk, $\mathcal{M}_4 \times I_r \times S_\theta^1$, Eq. (1)
I_r	the scale interval: the fifth dimension, the open fiber; coordinate $r = \ln(E_{\text{GUT}}/\mu)$, range $[0, K]$
S_θ^1	the phase circle: the sixth dimension, the compact fiber; coordinate θ
r	position along the interval — the descent’s depth, the RG address
θ	position around the circle — the gauge phase, the unreadable pointer
$(M, N, L; J, K)$	the integer ledger $(1, 3, 5; 7, 35)$, with $J = 2N + 1$ and $K = LJ$, Eq. (3)
$K = 35$	the depth of the descent in e-folds — the exponent of every interval-side scale
$J = 7$	the chiral steps of the flavor alphabet; also the corridor switch $z_{\text{sw}} = e^J$
$N_g = 3$	the number of fermion generations
$L = 5$	the rank structure of the unified group; the pentagonal lattice’s order
$W(C)$	the Wilson loop, Eq. (12) — the gauge-invariant content of a connection

continued on next page

Table 22 continued

Symbol	Meaning, and first use
$U(\theta)$	circle transport: a group element, invertible, Eq. (13)
$T(r)$	interval transport: a semigroup element, not invertible, Eq. (14)
ρ	the boundary density matrix; $\mathcal{D}[\rho]$ its dissipator, Eq. (5)
M_{lock}	the lock scale $\frac{1}{2}M_{\text{Pl}}e^{-K} = 3.849 \text{ TeV}$, Eq. (15)
$M_{\text{Pl,red}}$	the reduced Planck mass $(8\pi G_N)^{-1/2}$, Eq. (22)
v	the electroweak vacuum value, Eq. (9)
N^*	the observable e-fold count of the launch, 52.6
n_s, r_{T}	the scalar tilt and tensor-to-scalar ratio, Eq. (31)
$\Omega_m, \Omega_b, \Omega_\Lambda$	the matter, baryon, and dark-energy shares, Eq. (10)
m_K, f_K	the Kaxion's mass and decay constant, Eq. (32)
Ξ_{cap}	the cap loading $K + N + L = 43$ (benchmark; the one open integer)
η_B	the baryon-to-photon ratio, Eq. (40)
$\bar{\theta}$	the QCD vacuum angle (Problem 9)
Q_B	the Arisaka constant: the energy price of one bit (Problem 14)
S_{BH}	the Bekenstein–Hawking entropy, Eq. (49)
ζ_Λ	the drainage factor of the vacuum seesaw — named, bounded, uncomputed

63 Holonomy, connections, and the two transport algebras

What this appendix teaches. Parallel transport worked on a sphere until the answer is obvious; the covariant derivative as the bookkeeping that makes comparison at a distance possible; curvature as the failure of transport to commute; holonomy, and the theorem that curvature does not determine it; the Wilson loop as the gauge-invariant content of a connection; Aharonov–Bohm as the experiment that makes the whole apparatus physical; and finally the algebraic fork — group on a compact fiber, semigroup on an open one — that the rest of this course spends. Pay-off: Part II and every appendix after this one.

Read alongside: Nakahara (2003), Ch. 7 and 10, for connections on fiber bundles; Misner et al. (1973), Ch. 8 and 11, for the gravitational case with the pictures drawn; Wu and Yang (1975) for the statement that the holonomies *are* the gauge field.

63.1 Step 1 — the standard treatment: transport, curvature, holonomy

Transport on a sphere. Stand at the north pole holding an arrow that points down the Greenwich meridian. Walk south to the equator, keeping the arrow as parallel to itself as the surface permits — never twisting it about the local vertical. Turn left, walk a quarter of the way round the equator, then walk north again to the pole. The arrow now points ninety degrees from where it started. Nothing rotated it: at every step it was carried as parallel as the geometry allowed, and it came back turned.

The general statement is that transport around a closed circuit C bounding a region Σ rotates a tangent vector on the unit sphere by the enclosed solid angle,

$$\Delta\alpha = \Omega(\Sigma) = \oint_C (1 - \cos\vartheta) d\varphi, \quad (53)$$

with ϑ the polar angle. For the octant walked above, $\Omega = 4\pi/8 = \pi/2$, a quarter turn. Two features of Eq. (53) carry into everything below: the answer depends on the *loop*, not on any point of it, and it is insensitive to how the loop is deformed as long as the enclosed region's curvature integral is unchanged.

Connection and covariant derivative. To compare a field ψ at neighboring points one needs a rule for transporting the internal frame. Writing that rule as a connection one-form A_μ , the derivative that respects it is

$$D_\mu = \partial_\mu - \frac{iq}{\hbar} A_\mu, \quad (54)$$

where q is the charge — the strength with which ψ 's phase is geared to the connection. Finite transport along a path γ is the path-ordered exponential

$$U(\gamma) = \mathcal{P} \exp \left(\frac{iq}{\hbar} \int_\gamma A_\mu dx^\mu \right), \quad (55)$$

which is Eq. (12) evaluated on an open path rather than a loop.

Curvature is the failure of transport to commute. Transport around an infinitesimal parallelogram in the $\mu\nu$ -plane and compare with the reverse order:

$$[D_\mu, D_\nu] = -\frac{iq}{\hbar} F_{\mu\nu}, \quad F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \text{ (+ commutator, non-abelian)}. \quad (56)$$

Curvature is therefore not an extra postulate but the *definition* of how badly transport depends on the route.

Holonomy, and why curvature does not exhaust it. For a closed loop, Eq. (55) becomes the holonomy $W(C)$ of Eq. (12). In the abelian case Stokes' theorem gives $W(C) = \exp(iq\Phi/\hbar)$ with Φ the enclosed flux, so one might conclude that holonomy is merely an integral of curvature. It is not. If the region enclosed is not simply connected — if the loop wraps something — there exist configurations with $F_{\mu\nu} = 0$ everywhere along the loop and $W(C) \neq 1$. The Aharonov–Bohm phase of Eq. (11) is exactly this case, and it is measured. Holonomy is strictly more information than curvature; it is the connection's *topological* content.

Worked example: the flux quantum. Demand that the wavefunction of a charge q encircling a solenoid be single-valued. Then $q\Phi/\hbar$ must be a multiple of 2π , so the physically distinguishable fluxes are

$$\Phi = n \frac{h}{q}, \quad n \in \mathbb{Z}. \quad (57)$$

The observable is not the flux but the flux modulo h/q , and the integer n counting the quanta passed is protected: no continuous deformation of the field can change an integer.

The bundle, defined once. The object all of this lives on is a *fiber bundle*: a base manifold B , a fiber F , a total space E , and a projection $\pi : E \rightarrow B$ such that every point of B has a neighborhood U with $\pi^{-1}(U) \cong U \times F$. The last clause is the whole subtlety — the bundle looks like a product *locally*, and may fail to be one globally. Two local trivializations over overlapping patches are related by a transition function $t_{ij} : U_i \cap U_j \rightarrow G$ valued in the structure group, and it is the transition functions, not the fibers, that carry the topology. For $G = \text{U}(1)$ over a two-sphere the possible bundles are labeled by an integer — the first Chern number — and that integer is the monopole charge, which is Eq. (57) arriving by a different road.

Physics intuition. A gauge field is not a field *on* spacetime in the way a temperature is; it is a rule for comparing internal frames at different points, and the rule can be globally inconsistent in ways no local measurement reveals. Everything protected in this paper is a global inconsistency counted by an integer.

Parallel transport as an ordinary differential equation. Given a curve $x^\mu(\lambda)$ and a connection, the transported frame $U(\lambda)$ obeys

$$\frac{dU}{d\lambda} = \frac{iq}{\hbar} A_\mu \frac{dx^\mu}{d\lambda} U, \quad U(0) = \mathbb{K}, \quad (58)$$

whose solution is Eq. (55). For a vector on a Riemannian manifold the same equation reads $dV^a/d\lambda + \Gamma^a_{bc} V^b dx^c/d\lambda = 0$ with Γ the Christoffel symbols. Nothing is postulated here: given a rule for infinitesimal comparison, finite comparison is its integral, and the integral is path-dependent whenever the rule fails to commute with itself.

The sphere, computed rather than described. On the unit sphere with metric $ds^2 = d\vartheta^2 + \sin^2\vartheta d\varphi^2$, the non-vanishing Christoffel symbols are $\Gamma^\vartheta_{\varphi\varphi} = -\sin\vartheta \cos\vartheta$ and $\Gamma^\varphi_{\vartheta\varphi} = \cot\vartheta$. Transport a vector along a circle of constant ϑ : writing the vector's angle relative to the local meridian as $\alpha(\varphi)$, the transport equation reduces to $d\alpha/d\varphi = -\cos\vartheta$, so after a full circuit

$$\Delta\alpha = -2\pi \cos\vartheta \equiv 2\pi(1 - \cos\vartheta) \pmod{2\pi}, \quad (59)$$

which is Eq. (53) for this loop and reproduces the walked octant when the path is assembled from meridians and a quarter-equator. The reader is urged to do this once by hand (Problem A.1); it converts holonomy from a definition into a fact about the world.

The non-abelian case, and why the exponential is ordered. When the connection is matrix-valued, transports along successive segments multiply in order, and the values at different points need not commute. Slicing the path into N pieces,

$$U(\gamma) = \lim_{N \rightarrow \infty} \prod_{k=N}^1 \exp\left(\frac{iq}{\hbar} A_\mu(x_k) \Delta x_k^\mu\right) \equiv \mathcal{P} \exp\left(\frac{iq}{\hbar} \int_\gamma A\right), \quad (60)$$

the product taken with later points to the left. The symbol $\mathcal{P}$ is not decoration: it is the instruction that makes Eq. (55) a solution of Eq. (58) rather than a naive exponential.

How much holonomy does curvature determine? The Ambrose–Singer theorem answers precisely: the Lie algebra of the holonomy group is spanned by the curvature $F_{\mu\nu}$ transported to a base point, over all points of the manifold. On a *simply connected* space this makes holonomy a function of curvature. On a space with non-contractible loops it does not: the theorem constrains the connected component of the holonomy group, and leaves the discrete part — the winding — untouched. That gap is exactly where Aharonov–Bohm lives, and where every protected integer in this paper is stored.

Aharonov–Bohm, quantitatively. A two-slit interferometer of slit separation a and screen distance D , with a solenoid of flux Φ threaded between the arms, has fringes displaced by

$$\delta y = \frac{\lambda D}{a} \frac{\Delta\varphi}{2\pi} = \frac{\lambda D}{a} \frac{q\Phi}{h}, \quad (61)$$

with $\Delta\varphi$ from Eq. (11) and λ the de Broglie wavelength. A whole-fringe shift therefore requires exactly one flux quantum h/q . *Physics intuition:* the electron never visits the field; what it visits is a region where the *connection* is non-trivial, and the interferometer reads the loop integral because interference is, by construction, a comparison of two paths that meet again.

63.2 Step 2 — what the standard treatment leaves unexplained

Three gaps, each of which becomes one of Part I’s sixteen.

First, the status of the connection. Textbooks introduce A_μ as a device that repairs the non-invariance of $\partial_\mu\psi$ under a position-dependent phase change, then observe that the repair *predicts* electromagnetism. But a device introduced to fix a bookkeeping problem is not supposed to dictate a force. What the compact direction *is*, physically, is not answered — only that the mathematics behaves as though one existed (Problem 3).

Second, the origin of the integer. Eq. (57) required single-valuedness around a loop that encircles something. Where in the world is that loop? In four-dimensional field theory the compactness is imported — as a solenoid, as a boundary condition, as a choice of gauge group — never derived. Charge quantization is then observed rather than explained (Problem 4).

Third, the arrow. Nothing in Eqs. (54)–(56) distinguishes a direction in which transport is irreversible. Yet physics is full of transports that run one way: coarse-graining, measurement, the cosmic descent. The standard formalism supplies a group of transports and then imports irreversibility from outside — initial conditions, tracing, thermodynamic assumptions (Problems 1, 13, 14).

63.3 Step 3 — the two-fiber resolution

The anatomy answers all three by making the compactness a fact about the bulk and then asking what the same formalism does on the *other* fiber.

On the circle. S_θ^1 is compact, so $\pi_1(S_\theta^1) = \mathbb{Z}$: loops come in homotopy classes labeled by an integer winding. Every path around it closes, so every transport is a holonomy; the holonomies form a *group*, Eq. (13), in which each element has an inverse; and the winding integer is protected exactly as in Eq. (57) — not by a dynamical mechanism but because $\mathbb{Z}$ is discrete and nothing continuous can move between its points. This is why charge is quantized without a solenoid, why anomaly coefficients cannot run, and why class data are the same in every region of the sky.

On the interval. $I_r = [0, K]$ is contractible and has boundary: $\pi_1(I_r)$ is trivial, and there is no closed circuit along it. Whatever a connection does there carries no gauge-invariant loop content — the precise sense of “the interval forgets.” The physical transport along r is the renormalization flow / cosmic descent, which composes only forward:

$$T(r_2)T(r_1) = T(r_1 + r_2) \quad (r_i \geq 0), \quad T(r) \text{ has no inverse,} \quad (62)$$

Eq. (14) again. The absence of an inverse is not a modeling choice: coarse-graining destroys the information needed to undo it, and no operation restores what was never kept.

The fork, stated once. A connection on a compact fiber gives a group of protected classes; the same connection on an open fiber gives a semigroup of final acts. One geometry, two algebras, and — the claim of this paper — sixteen problems sorted by which algebra their subject matter lives in.

The connection, decomposed by fiber. Write the bulk connection in coordinates adapted to Eq. (1):

$$A = A_\mu(x, r, \theta) dx^\mu + A_r(x, r, \theta) dr + A_\theta(x, r, \theta) d\theta. \quad (63)$$

Three statements follow, and they are the technical content of “the circle remembers; the interval forgets.”

(i) *The dr component carries nothing.* Because I_r is an interval — contractible, with boundary — one may always choose the axial gauge $A_r = 0$ by a gauge transformation $g(x, r, \theta) = \mathcal{P} \exp\left(\frac{iq}{\hbar} \int_0^r A_{r'} dr'\right)$, which is globally well defined precisely because the integration path is unique up to homotopy. No residual invariant survives: there is no closed circuit in r on which to evaluate anything.

(ii) *The $d\theta$ component carries a modulus that cannot be gauged away.* On the circle the analogous transformation would require $g(\theta + 2\pi) = g(\theta)$, so the available shifts of the Wilson line

$$W_\theta = \mathcal{P} \exp\left(\frac{iq}{\hbar} \oint A_\theta d\theta\right) = e^{i\alpha} \quad (64)$$

are quantized, $\alpha \rightarrow \alpha + 2\pi n$. The residual $\alpha \in [0, 2\pi)$ is a physical, gauge-invariant modulus — a coordinate on the space of flat connections — and it is exactly what Problem A.5 computes and what the Hosotani mechanism (Hosotani, 1983) makes dynamical.

(iii) *The classification is topological, not dynamical.* Flat connections on S_θ^1 modulo gauge transformations form the space $\text{Hom}(\pi_1(S^1), G)/G = G/\text{Ad}(G)$, which for $U(1)$ is the circle of values α ; on I_r the same construction gives $\text{Hom}(\{1\}, G)/G$ — a single point. One fiber has a moduli space of protected data; the other has nothing to have.

The semigroup, constructed rather than asserted. That interval transport lacks inverses can be shown explicitly with the oldest construction in the subject. Kadanoff blocking on a lattice of spacing a replaces each block of b^d sites by one effective site with spacing ba , defining a map $\mathcal{R}_b$ on the space of couplings $\{g\}$:

$$\mathcal{R}_{b_2} \circ \mathcal{R}_{b_1} = \mathcal{R}_{b_1 b_2}, \quad \mathcal{R}_b^{-1} \text{ does not exist.} \quad (65)$$

The composition law is exact — blocking twice is blocking once at the product ratio — and the inverse fails for a reason that is not technical: many microscopic configurations map to the same block configuration, so $\mathcal{R}_b$ is not injective (Problem A.4 makes this concrete in two states). Eq. (65) is Eq. (14) with $r = \ln b$, and it is why the fifth dimension’s coordinate is logarithmic in scale: the natural composition is multiplication of ratios, whose additive coordinate is the logarithm.

What the two structures then buy, itemized. Every exactness claim in this paper traces to the integrality in (ii) and (iii) — the quantized shifts and the winding classes, *not* the continuous residual α , which is a modulus and does move — and every irreversibility claim to Eq. (65). Charge quantization: the winding integer of $\pi_1(S_\theta^1) = \mathbb{Z}$. Anomaly coefficients that cannot run: integers labeling bundles, and $\mathcal{R}_b$ acts trivially on $\mathbb{Z}$ because it is continuous and $\mathbb{Z}$ is discrete. Class data identical across the sky: a homotopy class is not a local field and has no gradient to vary. Measurement’s finality, entropy’s growth, the descent’s one traverse: the missing inverse in Eq. (65). Two lines of topology, one line of algebra, and the sixteen problems sorted.

63.4 Step 4 — problems and worked solutions

A.1. Verify Eq. (53) for a loop of constant latitude ϑ , and show that a small loop sees a flat world.

Solution. Step 1. At fixed ϑ , $\oint (1 - \cos \vartheta) d\varphi = 2\pi(1 - \cos \vartheta)$. *Step 2.* Expanding for small ϑ , $2\pi(1 - \cos \vartheta) \rightarrow \pi\vartheta^2$, which is the enclosed area. *Step 3.* So the holonomy is second order in the loop size — curvature times area. *Physics intuition:* local experiments cannot detect curvature, which is precisely why curvature had to be discovered by comparing distant transports rather than by looking closely at one point.

A.2. Show that $F_{\mu\nu}$ of Eq. (56) is gauge covariant but not gauge invariant in the non-abelian case, and identify what is invariant.

Solution. Step 1. Under a gauge transformation $A_\mu \rightarrow UA_\mu U^{-1} + (i\hbar/q)U\partial_\mu U^{-1}$ one finds $F_{\mu\nu} \rightarrow UF_{\mu\nu}U^{-1}$. *Step 2.* That is covariance: F changes unless U commutes with it, so F itself is not observable. *Step 3.* Traces — $\text{Tr}(F_{\mu\nu}F^{\mu\nu})$ — and the Wilson loop Eq. (12) are invariant. *Physics intuition:* in electromagnetism the group is one-dimensional, covariance collapses to invariance, and one may treat $\vec{E}$ and $\vec{B}$ as observables directly; Yang–Mills denies that convenience, which is why the loop language is the right one in general.

A.3. Two configurations outside a solenoid have identical F everywhere but fluxes differing by h/q . Are they distinguishable?

Solution. Step 1. By Eq. (11) the interference phases differ by 2π . *Step 2.* A phase of 2π is no phase at all. *Step 3.* They are *indistinguishable* — the content of Eq. (57). *Physics intuition:* the world does not record the flux; it records the flux modulo a quantum, and the integer left over is the only part that cannot be deformed away. Every protected quantity in this paper is an integer of this type.

A.4. Show explicitly that a coarse-graining map has no inverse, using a two-state example.

Solution. Step 1. Let the map send both $|0\rangle\langle 0|$ and $|1\rangle\langle 1|$ to the maximally mixed state $\frac{1}{2}\mathbb{I}$. *Step 2.* Two distinct inputs share one output, so the map is not injective. *Step 3.* A non-injective map has no inverse; the family $\{T(r)\}$ built from such maps is therefore a semigroup, not a group, which is Eq. (62). *Physics intuition:* irreversibility in this paper is never a statistical approximation to reversible microphysics; it is the failure of injectivity, and failures of injectivity do not become injective when one looks more carefully.

A.5. A circle of circumference $2\pi R$ carries a flat connection with holonomy $e^{i\alpha}$. Show that α cannot be removed by a gauge transformation, and identify what physical effect it has.

Solution. Step 1. A gauge transformation $e^{i\chi(\theta)}$ must be single-valued on the circle, so $\chi(2\pi) - \chi(0) \in 2\pi\mathbb{Z}$. *Step 2.* It can therefore shift α only by multiples of 2π , not to zero. *Step 3.* The residual α is physical: it shifts the Kaluza–Klein spectrum of charged fields to $m_n \propto (n + \alpha/2\pi)/R$. *Physics intuition:* this is the Wilson-line (Hosotani) vacuum of Problem 2 — a circle-side label with laboratory consequences, and the mechanism by which a compact direction sets a mass scale without any field being given a potential by hand.

Take-away. A connection *is* its holonomies; holonomies need loops; loops need compactness. On a compact fiber that yields a group of protected integers, on an open fiber a semigroup of final acts. Every later appendix is an application of this one paragraph.

64 Open quantum systems, decoherence, and the write

What this appendix teaches. The density matrix and the partial trace, derived; the Lindblad master equation and why its form is forced by complete positivity; decoherence computed, with the $(\Delta x)^2$ scaling that Figure 8 plots; the measurement postulates as they are actually taught; and then the honest accounting of what decoherence does and does not deliver — and what the two-fiber reading adds. Pay-off: Problem 1.

Read alongside: Nielsen and Chuang (2000), Ch. 2 and 8, for density matrices and quantum operations; Breuer and Petruccione (2002), Ch. 3, for the Lindblad derivation; Zurek (2003) for the decoherence program in the author’s own words.

64.1 Step 1 — the standard treatment: from pure states to master equations

Why a density matrix. A system entangled with anything else has no state vector of its own. Given a joint pure state $|\Psi\rangle$ of system S and environment E , all predictions for measurements on S alone are reproduced by the reduced density matrix

$$\rho_S = \text{Tr}_E |\Psi\rangle\langle\Psi|, \quad (66)$$

the partial trace. Two facts about Eq. (66) matter for everything below: it is the unique map reproducing all local expectation values, and it is *not invertible* — distinct joint states routinely give the same ρ_S .

The forced form of the dynamics. Ask what the most general time evolution of ρ_S can be, subject only to: it preserves trace (probabilities sum to one), it preserves positivity even when S is entangled with a spectator (complete positivity), and it is Markovian (no memory). The answer — the Gorini–Kossakowski–Sudarshan–Lindblad theorem — is unique in form:

$$\frac{d\rho}{dt} = -\frac{i}{\hbar}[H, \rho] + \sum_k \gamma_k \left(L_k \rho L_k^\dagger - \frac{1}{2}\{L_k^\dagger L_k, \rho\} \right), \quad (67)$$

with $\gamma_k \geq 0$. This is Eq. (5) written with its dissipator opened up: H generates the reversible part, the jump operators L_k (with rates γ_k) generate the irreversible part. The positivity of every γ_k is the whole story of the arrow at this level — reverse the sign of one and probabilities go negative.

Decoherence, computed. Take S a massive particle coupled to a scattering environment, with $L \propto \hat{x}$. Then Eq. (67) gives, in the position basis,

$$\frac{\partial}{\partial t} \rho(x, x') = \cdots - \Lambda (x - x')^2 \rho(x, x'), \quad \rho(x, x', t) \sim e^{-\Lambda(\Delta x)^2 t}, \quad (68)$$

where Λ is the scattering constant of the environment (collision rate times momentum transfer squared, in units of $\hbar^2$). The diagonal — the probabilities — is untouched; the off-diagonal — the interference — decays at a rate $\Gamma = \Lambda(\Delta x)^2$, quadratic in the separation of the superposed alternatives. That quadratic law is the line plotted in Figure 8, and it is why a dust grain superposed over a micron loses coherence in $\sim 10^{-24}$ s while an electron over an Ångström can hold it for seconds. (Both numbers use Λ in SI units; the standard tabulations are quoted in $\text{cm}^{-2}\text{s}^{-1}$, and the four-order conversion is the commonest slip in this calculation.)

The measurement postulates, as taught. Alongside Eq. (67) the textbook still states, separately: observables are Hermitian operators; between measurements states evolve by Eq. (16); a measurement yields eigenvalue k with probability $p_k = \text{Tr}(P_k \rho)$ and updates the state by Eq. (17).

Quantum channels, and the theorem that constrains them. Before the master equation there is a more primitive question: what maps $\rho \rightarrow \mathcal{E}(\rho)$ are physically allowed? The answer — Kraus' theorem — is that $\mathcal{E}$ is completely positive and trace preserving if and only if it can be written

$$\mathcal{E}(\rho) = \sum_k E_k \rho E_k^\dagger, \quad \sum_k E_k^\dagger E_k = \mathbb{I}, \quad (69)$$

for some operators E_k . The proof is constructive: couple the system to an environment, evolve unitarily, and trace — the E_k are the matrix elements of the joint unitary in an environment basis. Every open evolution in physics has this form, and Eq. (67) is its infinitesimal version (Problem B.6).

Physics intuition. Complete positivity is not a technicality. It is the demand that the map remain sensible when the system is merely *part* of a larger entangled state — and it is what forbids the time-reversed dissipator, because running Eq. (69) backwards generically produces negative probabilities on some entangled input.

From a microscopic model to Eq. (67). Take $H = H_S + H_E + \lambda H_{\text{int}}$ with $H_{\text{int}} = \sum_{\alpha} S_{\alpha} \otimes E_{\alpha}$. In the interaction picture, expand to second order in λ , trace over the environment, and impose two approximations: *Born* (the environment is large, so $\rho_{SE} \approx \rho_S \otimes \rho_E$ throughout) and *Markov* (environment correlation functions $\langle E_{\alpha}(t) E_{\beta}(t') \rangle$ decay fast compared with the system's evolution). The result is the Redfield equation, and a final secular average over fast phases brings it to Lindblad form with

$$\gamma_{\alpha\beta}(\omega) = \int_{-\infty}^{\infty} dt e^{i\omega t} \langle E_{\alpha}^{\dagger}(t) E_{\beta}(0) \rangle, \quad (70)$$

the Fourier transform of the environment correlation function. Positivity of γ follows from Bochner's theorem: a correlation function's transform is a positive measure. The arrow is therefore inherited from the environment's *spectrum*, which is the first hint that it is structural rather than dynamical.

A two-level model, solved completely. Let $H_S = \frac{\hbar\omega_0}{2}\sigma_z$ and take a single dephasing channel $L = \sqrt{\gamma}\sigma_z$. Then Eq. (67) separates:

$$\dot{\rho}_{00} = \dot{\rho}_{11} = 0, \quad \dot{\rho}_{01} = (-i\omega_0 - 2\gamma)\rho_{01} \implies \rho_{01}(t) = \rho_{01}(0) e^{-i\omega_0 t} e^{-2\gamma t}. \quad (71)$$

Populations are untouched; coherences decay exponentially. This is the whole of decoherence in four lines, and every elaboration — position bases, continuous variables, many environments — is a dressing of Eq. (71).

Where the $(\Delta x)^2$ comes from. For a particle scattering off environmental quanta of typical momentum transfer $\hbar k$, each collision multiplies the off-diagonal element by $\langle e^{ik(x-x')} \rangle$. For small separations this is $1 - \frac{1}{2}\langle k^2 \rangle (x-x')^2$, so with a collision rate Γ_{coll} the damping constant of Eq. (68) is $\Lambda \simeq \frac{1}{2}\Gamma_{\text{coll}}\langle k^2 \rangle$. *Physics intuition:* decoherence is not the environment “disturbing” the system — the recoil is negligible — but the environment *learning* which path was taken; the rate is set by how well one scattering distinguishes them, which is why it is quadratic in the separation and saturates once a single collision resolves the two alternatives.

The einselection criterion. Among all bases, the pointer basis is the one whose states are least damaged by the interaction: operationally, those commuting with H_{int} , or — when the self-Hamiltonian competes — those minimizing the entropy production rate over time (Zurek's predictability sieve). For H_{int} a function of position, position wins, which is why the classical world looks spatial.

64.2 Step 2 — what the standard treatment leaves unexplained

Decoherence is a genuine and quantitative success — and it is important to say exactly what it does not do, because the honest list is short and sharp.

It does not select the basis without help. The calculation above assumed $L \propto \hat{x}$: position was put in by hand through the form of the coupling. The predictability-sieve argument justifies that choice from the interaction Hamiltonian — but the interaction Hamiltonian is itself part of the description whose structure is being asked about.

It does not produce the Born measure. $p_k = \text{Tr}(P_k \rho)$ is used to interpret ρ from the start. Nothing in Eq. (67) derives the squared-amplitude rule; the equation is written in a language that presupposes it.

It does not produce a single outcome. Eq. (68) turns a coherent superposition into a diagonal ensemble; an ensemble is not an event. The transition from “these are the odds” to “this one happened” remains outside the formalism.

It does not say where the environment came from. The split between S and E in Eq. (66) is a choice of description, and the theory is silent on why the world offers one. This is Problem 1 in its sharpest technical form.

64.3 Step 3 — the two-fiber resolution

The environment is named, and it is not optional. OGGEF makes the partial trace of Eq. (66) compulsory rather than elective: the boundary observer cannot resolve the fiber coordinates (r, θ) , so every registration marginalizes them (Figure 2). The “environment” is not a modeling convenience but the two hidden directions, and the projection is always on. That is why Eq. (67) is not an effective description of a closed system we are too clumsy to track, but the exact form of boundary dynamics.

The two terms are the two fibers. The commutator is the circle’s transport — Eq. (13), invertible, phase-carrying. The dissipator is the interval’s — Eq. (14), one-way, record-forming. The $\gamma_k \geq 0$ that the Lindblad theorem imposes as a consistency condition is, on the anatomy, a statement about which fiber the term rides: transports along an open fiber cannot have inverses, so their rates cannot be negative.

The basis, the measure, and the outcome. The preferred basis is the one the projection can reach — the quantities that survive marginalizing (r, θ) , which is why position-like and class-like variables are the classical ones. The Born measure is produced rather than assumed: the dissipator relaxes configurational statistics onto $|\langle k|\psi\rangle|^2$ monotonically, at a rate the port coupling sets, and the chain is closed at the relaxation level with exactly one named residue — the field-grade representation step — declared open (grade: derived-conditional). And the single outcome is the write itself: an interval-side deposit with no inverse, which is what Eq. (17) describes in its completed limit.

What this buys, and what it costs. It buys a measurement account with no extra postulate and one honest residue; it costs an exposure — if Born statistics are relaxed into rather than axiomatic, the largest cosmological scales should carry the computable deficit of Eq. (18), and exact Born statistics at all scales bounds the relaxation time from below.

The projection, written as a channel. Make the claim of §64.3 explicit. A boundary observer’s state is obtained from the bulk state by integrating out the fiber coordinates,

$$\rho_4(x, x') = \int_{I_r} dr \oint_{S_\theta^1} d\theta \rho_6((x, r, \theta), (x', r, \theta)), \quad (72)$$

which is Eq. (66) with the environment named. By Kraus’ theorem Eq. (69) this map is a channel, and by the argument of Problem B.1 it is not injective: bulk states differing only in their fiber dependence give the same ρ_4 . OGGEF says this integration is not optional — there is no boundary protocol that resolves (r, θ) — so the projection is compulsory rather than a modeling convenience. Lindblad form then follows once the third hypothesis of §64.1 is supplied, and the honest register requires naming it: the boundary dynamics must be Markovian, which here is a physical statement about how fast the fiber correlations decay and *not* a consequence of the projection. The three steps are distinct and all three are needed — non-injectivity gives a channel, OGGEF makes the channel compulsory, Markovianity gives it a generator — and the third is the one

a critical reader should press hardest, since non-Markovian open dynamics is generic. With it, the two terms of Eq. (5) are the two fibers’ contributions to Eq. (70).

Which fiber supplies which term. The assignment is *algebraic*, and one tempting way to argue it is wrong, so this paragraph disposes of the temptation before making the argument that works.

The spectral argument does not run here. It is natural to say that a compact fiber has a discrete spectrum and therefore cannot supply the continuum of final states irreversibility requires, while an open fiber can. That would be a clean derivation if I_r were a half-line. It is not: $I_r = [0, K]$ is a finite segment with boundary, and under any self-adjoint boundary condition its spectrum is discrete — this is the particle in a box. Worse for the argument, its level spacing is not small but the *largest* in the framework, because it is the Kaluza–Klein spacing that puts the lock cluster at 3.849 TeV and gives Problem 2 its collider target. A bath whose levels are that far apart is no drain at all. The two fibers are a circle and a segment: both compact, both with discrete spectra, and no spectral property distinguishes them. The paper says so here rather than leaving it for a critic, because the slogan “a perfect memory and a perfect drain” is an image and not a theorem.

What does distinguish them is the composition law, and it needs no spectral input at all. Transport around S_θ^1 has an inverse, Eq. (13); the physical flow along I_r does not, Eq. (65), because blocking is not injective. A generator built from a one-parameter family closed under inversion is anti-Hermitian, and contributes the commutator of Eq. (67); a generator built from a family that admits no inverse is what that same equation calls a dissipator, and its rates are non-negative for the same reason the family is one-way. That is the technical content of “the commutator is the circle’s and the dissipator is the interval’s,” it is premise (D) of §13 doing exactly the work premise (T) cannot, and it is a statement about algebra rather than about level spacings.

Physics intuition. Irreversibility needs information to go somewhere it cannot be retrieved from, and there are two ways to arrange that. One is to make the somewhere large: the ordinary bath, where recurrence is merely slow, where the argument is statistical, and where the conclusion is approximate — which is precisely the weakness this paper charges against decoherence. The other is to make the retrieval *structurally unavailable*, which is what OGGEF does: the boundary observer has no protocol that resolves (r, θ) , so the trace of Eq. (72) is compulsory rather than convenient. The interval is not a better bath than the circle. It is the fiber along which the compulsory projection has nothing to give back — because, by (T), there was never a gauge-invariant record there to return.

The Born measure as a relaxation, and its residue. Write the boundary’s configurational weight over outcomes as $\{w_k\}$ and let $p_k = |\langle k|\psi\rangle|^2$ denote the squared amplitudes. The boundary law’s dissipation produces a gradient flow on the simplex,

$$\dot{w}_k = -\Gamma \frac{\partial}{\partial w_k} D(w \| p), \quad D(w \| p) = \sum_k w_k \ln \frac{w_k}{p_k} \geq 0, \quad (73)$$

with D the relative entropy and Γ set by the port coupling. Since $D \geq 0$ with equality only at $w = p$, and $\dot{D} \leq 0$ along the flow — the descent of the relative entropy to a stationary state that any completely positive semigroup carries (Lindblad, 1975; Spohn, 1978) — the weights relax monotonically to the Born measure and stay there. Two things must be said plainly. Eq. (73) is a *result* of the boundary law’s dissipative structure, not an assumption — that is the content of the cohort’s Born chain, carried at derived-conditional grade. And the one step still owed is the field-grade representation — showing that the boundary’s coarse-grained weights are exactly the w_k of Eq. (73) in a relativistic field theory rather than in the finite-dimensional model. That residue is named here, in the honest ledger, and in Problem 1.

Why the relaxation is observable. A relaxation takes time, and any mode that decoupled before it finished retains the pre-relaxation statistics. Modes that left the horizon during inflation are exactly such a population, which gives the deficit of Eq. (18), $\xi(k) = 1 - A(k/k_0)^{-\gamma}$ — the sharpest available distinction between “Born is an axiom” (no deficit at any scale) and “Born is an attractor” (a computable deficit on the largest scales). No interpretation of quantum mechanics has previously carried an observational signature at all; this one does, and it is the reason Problem 1 sits in a physics paper rather than a philosophy one.

64.4 Step 4 — problems and worked solutions

B.1. Show that the partial trace is the unique map reproducing all local expectation values.

Solution. Step 1. Require $\text{Tr}(\rho_S O) = \text{Tr}(\rho_{SE} O \otimes \mathcal{K})$ for every system observable O . *Step 2.* Expanding in a basis of operators, the condition fixes every matrix element of ρ_S as $\sum_e \langle s, e | \rho_{SE} | s', e \rangle$. *Step 3.* That is Eq. (66), and no freedom remains. *Physics intuition:* the reduced state is not an approximation — it is exactly what is knowable locally, which is why the information it drops is dropped irrevocably rather than merely hidden.

B.2. Show that a negative γ_k in Eq. (67) violates positivity.

Solution. Step 1. Take a single jump operator $L = |0\rangle\langle 1|$ and initial state $\rho = |0\rangle\langle 0|$. *Step 2.* With $\gamma < 0$ the population of $|0\rangle$ grows without a compensating loss elsewhere, and after finite time the population of $|1\rangle$ goes negative. *Step 3.* Negative probability is inconsistent, so $\gamma \geq 0$. *Physics intuition:* the arrow of the dissipator is not an extra assumption bolted onto quantum mechanics; it is what consistency permits once the dynamics is open at all.

B.3. Estimate the decoherence time of a $10\ \mu\text{m}$ dust grain superposed over $1\ \mu\text{m}$ in air, given $\Lambda \sim 10^{36}\ \text{m}^{-2}\text{s}^{-1}$.

Solution. Step 1. From Eq. (68), $\Gamma = \Lambda(\Delta x)^2 = 10^{36} \times (10^{-6})^2 = 10^{24}\ \text{s}^{-1}$. *Step 2.* The coherence time is $\Gamma^{-1} = 10^{-24}\ \text{s}$. *Step 3.* Compare the light-travel time across the grain, $\sim 3 \times 10^{-14}\ \text{s}$: decoherence is ten orders faster than anything mechanical in the problem. *Physics intuition:* macroscopic superpositions are not forbidden, they are *unaffordable* — and the price is set by how loudly the alternatives differ, which is the $(\Delta x)^2$.

B.4. Show that Eq. (68) leaves the diagonal untouched, and explain why this matters for Problem 1.

Solution. Step 1. Set $x = x'$: the damping factor $(x - x')^2$ vanishes. *Step 2.* Hence $\rho(x, x)$ — the probability density — obeys the same equation it would without the environment. *Step 3.* Decoherence therefore destroys interference without changing any probability. *Physics intuition:* this is exactly why decoherence cannot be the whole answer to the measurement problem: it explains why we never see the interference, and says nothing about why we see one outcome. The write of Step 3 is what the diagonal still needs.

B.5. A student objects: “unitarity is sacred, so the write cannot be fundamental.” Answer them.

Solution. Step 1. Unitarity is a property of the *bulk* books, and the anatomy keeps them exact — Problem 16 runs the same argument across a horizon. *Step 2.* What is not unitary is the boundary *reading*, and no theorem ever said a marginal of a unitary evolution is unitary; the partial trace of B.1 is a counterexample by construction. *Step 3.* The contradiction the student fears arises only if one insists the reading be described by the books’ own dynamics — the one-fiber assumption. *Physics intuition:* a ledger can be exact while every page you are allowed to photocopy is smudged; the smudging is the projection, not a failure of the ledger.

B.6. Derive Eq. (67)’s structure from Eq. (69) for a short time step.

Solution. Step 1. Write $E_0 = \mathbb{K} + (-\frac{i}{\hbar}H - \frac{1}{2}\sum_k \gamma_k L_k^\dagger L_k)\delta t$ and $E_k = \sqrt{\gamma_k \delta t} L_k$ for $k \geq 1$; the completeness relation holds to $O(\delta t)$. *Step 2.* Substituting into Eq. (69) and keeping terms of order δt gives $\rho + \delta t(-\frac{i}{\hbar}[H, \rho] + \sum_k \gamma_k (L_k \rho L_k^\dagger - \frac{1}{2}\{L_k^\dagger L_k, \rho\}))$. *Step 3.* Dividing by δt returns Eq. (67). *Physics intuition:* the Lindblad form is not a model of dissipation but the most general thing that can happen to a piece of a larger quantum world in a short time — which is why deriving the boundary law from a projection, as Step 3 does, lands on it rather than on something exotic.

Take-away. Open-system quantum mechanics is not an approximation scheme in this reading but the exact boundary law, with the commutator riding the circle and the dissipator the interval. What the standard account imports — the environment, the basis, the measure — the anatomy names; what it cannot deliver — the single outcome — the anatomy identifies as the write, and prices it with one declared residue.

65 Gauge invariance and the renormalization group

What this appendix teaches. The gauge principle derived from the demand for a position-dependent phase; Noether's two theorems and why the second one changes the meaning of the first; the beta function and the one-loop running computed; asymptotic freedom; the anomaly and why its coefficient is an integer — and then the two-fiber reading in which the first half of this chapter is the circle and the second half is the interval. Pay-off: Problems 2 and 3.

Read alongside: [Peskin and Schroeder \(1995\)](#), Ch. 15 and 12, for non-abelian gauge fields and the renormalization group; [Weinberg \(1995\)](#), Ch. 7, for the careful treatment of Noether's theorems; [Srednicki \(2007\)](#), Ch. 72–73, for anomalies computed cleanly.

65.1 Step 1 — the standard treatment

The gauge principle. Start from a free complex field with Lagrangian $\mathcal{L} = \bar{\psi}(i\gamma^\mu \partial_\mu - m)\psi$ and demand invariance under the *local* phase change of Eq. (23). The derivative term spoils it, by a residue proportional to $\partial_\mu \chi$. Replacing $\partial_\mu \rightarrow D_\mu$ with Eq. (54) and assigning A_μ the compensating shift restores invariance — and in doing so introduces a vector field with a definite coupling to every charge. Repeating with a non-abelian group gives the Yang–Mills Lagrangian

$$\mathcal{L}_{\text{YM}} = -\frac{1}{4}F_{\mu\nu}^a F^{a\mu\nu} + \bar{\psi}(i\gamma^\mu D_\mu - m)\psi, \quad (74)$$

whose self-interactions follow from the commutator term in Eq. (56). Nothing was added by hand except the demand.

Noether's two theorems. For a *global* symmetry with parameter ϵ , invariance of the action gives a conserved current, $\partial_\mu j^\mu = 0$ — a genuine constraint on motion. For a *local* symmetry with arbitrary $\chi(x)$, the same manipulation yields instead an *identity* among the equations of motion, true whether or not they are satisfied. This is the second theorem, and it is why a local symmetry supplies no new conserved charge: it says the description is redundant, not that the world is constrained.

Running couplings. Loop corrections make a coupling's measured value depend on the resolution scale μ . Writing the dependence infinitesimally gives Eq. (24), $\mu dg/d\mu = \beta(g)$, with the one-loop non-abelian

result

$$\beta(g) = -\frac{b_0}{16\pi^2} g^3, \quad b_0 = \frac{11}{3}C_A - \frac{4}{3}T_F n_f \xrightarrow{\text{SU}(3)} 11 - \frac{2}{3}n_f, \quad (75)$$

whose integral is Eq. (20). For QCD with $n_f \leq 16$, $b_0 > 0$ and the coupling *falls* toward the ultraviolet: asymptotic freedom. For QED the sign is reversed and the coupling grows with energy.

The anomaly. A symmetry of the classical action can fail to survive quantization because the path-integral measure is not invariant. The failure is one-loop exact and its coefficient is a sum of group-theory factors over the fermion content — the sums of Eq. (25). Consistency of a gauge theory requires those sums to vanish exactly; the fact that the Standard Model’s hypercharges do so, forcing quark charges to be thirds, is one of the most striking facts in particle physics.

Yang–Mills, assembled explicitly. For a group with generators T^a obeying $[T^a, T^b] = if^{abc}T^c$, write $A_\mu = A_\mu^a T^a$. Demanding covariance of $D_\mu \psi = (\partial_\mu - igA_\mu)\psi$ under $\psi \rightarrow U\psi$ forces $A_\mu \rightarrow UA_\mu U^{-1} + \frac{i}{g}U\partial_\mu U^{-1}$, and the field strength follows from Eq. (56):

$$F_{\mu\nu}^a = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + gf^{abc}A_\mu^b A_\nu^c. \quad (76)$$

The last term is the whole difference from electromagnetism: the gauge field carries the charge it couples to, so Eq. (74) contains three- and four-point self interactions with coefficients fixed — not fitted — by f^{abc} . *Physics intuition:* the gluon’s self-coupling is not an additional force law but the statement that color rotations do not commute; every distinctive feature of QCD, asymptotic freedom included, descends from that one non-commutation.

Quantization, gauge fixing, and ghosts, in brief. The path integral over A_μ overcounts by the volume of the gauge group. Faddeev and Popov’s device inserts $1 = \Delta_{\text{FP}} \int \mathcal{D}\chi \delta(G(A^\chi))$ with G a gauge condition, producing a gauge-fixing term and a determinant that is exponentiated as anticommuting “ghost” fields. Ghosts are not physical states; they are bookkeeping that removes the unphysical polarizations of A_μ in loops. The reader should retain one fact: the gauge redundancy is not eliminated by quantization, only *managed*, and every physical answer is independent of G .

The beta function, and where its two terms come from. At one loop the coupling’s scale dependence, Eq. (75), receives two competing contributions. *Fermion loops screen*, exactly as in QED: a virtual pair polarizes the vacuum, and the effective charge seen from far away is reduced — this is the $-\frac{4}{3}T_F n_f$ term, negative in b_0 and pushing toward a Landau pole. *Gluon loops antiscreen*: because the gluon carries color, the vacuum behaves as a paramagnetic medium whose induced color currents *enhance* the field — the $+\frac{11}{3}C_A$ term. With $C_A = 3$ and $T_F = \frac{1}{2}$ this gives $b_0 = 11 - \frac{2}{3}n_f$, positive for $n_f \leq 16$, so antiscreening wins and QCD is asymptotically free.

Physics intuition. The sign of b_0 is the single most consequential number in the strong interaction: positive means the force weakens at short distance (quarks look free inside a proton) and strengthens at long distance (they are never seen alone). Both faces of Problem 12 are contained in that sign.

The Callan–Symanzik equation. Physical quantities cannot depend on the arbitrary renormalization point, so an n -point function obeys

$$\left[\mu \frac{\partial}{\partial \mu} + \beta(g) \frac{\partial}{\partial g} + n\gamma(g) \right] G^{(n)}(\{x\}; g, \mu) = 0, \quad (77)$$

with γ the anomalous dimension. Eq. (77) says the explicit μ -dependence and the implicit dependence through $g(\mu)$ must cancel — and it is the formal statement that “running” is a statement about *descriptions*, not about nature changing with energy.

The anomaly, computed the quickest way. Consider the triangle diagram with one axial and two vector currents. Any regulator that preserves the vector Ward identities necessarily violates the axial one, giving

$$\partial_\mu j^{\mu 5} = \frac{g^2}{16\pi^2} \epsilon^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma}, \quad (78)$$

the Adler–Bell–Jackiw anomaly. Fujikawa’s derivation makes the origin transparent: the fermionic path-integral measure is not invariant under a chiral rotation, and its Jacobian is exactly Eq. (78). The coefficient is fixed by group theory alone — it receives no corrections at any order, by the Adler–Bardeen theorem. *Physics intuition:* an anomaly is what happens when a symmetry of the equations is not a symmetry of the *counting of states*; and since counting is discrete, the result is an integer that no amount of dynamics can shift.

65.2 Step 2 — what the standard treatment leaves unexplained

A redundancy that dictates. By Noether’s second theorem and Elitzur’s theorem, local gauge symmetry is a property of our labeling, not of states — and yet it fixes the interactions completely. A framework in which bookkeeping determines dynamics is either hiding a physical structure behind the bookkeeping or enjoying a remarkable coincidence. The textbook offers no way to decide (Problem 3).

An arrow with no owner. Eq. (75) is a first-order flow in $\ln \mu$ that runs one way: integrating out short distances is not invertible. The formalism records the one-wayness (the c -theorem and its relatives make it precise) but locates it nowhere — the four spacetime directions are all two-way (Problems 1, 13).

An integer with no home. Anomaly coefficients cannot receive corrections at any order; they are integers up to fixed normalizations. Integers are the signature of topology, but four-dimensional field theory has no compact direction to put them on — so their exactness is verified rather than explained (Problem 4).

65.3 Step 3 — the two-fiber resolution

Gauge invariance is the circle’s unreadability. If the phase θ is a coordinate on a real compact fiber, then a gauge transformation is precisely a re-zeroing of an *unreadable* pointer, and Eq. (23)’s arbitrary $\chi(x)$ is the statement that no experiment reads the absolute angle. What experiment *can* read is the loop total, Eq. (12). The century’s discomfort — how can a redundancy dictate a force? — dissolves: the redundancy is our inability to read a physical fiber, and the dictation is the fiber’s geometry showing through the only window that is open. The photon is the gearing between pointers and carries no dial of its own, which is why it is massless and chargeless.

Renormalization is motion along the interval. The coordinate $r = \ln(E_{\text{GUT}}/\mu)$ is the fifth dimension, so Eq. (24) is transport along I_r and Eq. (75) is its generator. Three textbook facts become statements about a fiber. Couplings are readings at addresses, not constants — hence no address is privileged. The flow’s irreversibility is Eq. (62), not an extra principle. And renormalizability — the survival of only a handful of operators — is the statement of what the descent can carry down without leaking.

The anomaly is the circle auditing the interval. Anomaly coefficients are winding data: integers on the compact fiber, which by construction cannot run under Eq. (75). Their vanishing is not a coincidence

of the matter content but the condition that the bulk’s books close — the six-dimensional instance being the Green–Schwarz mechanism of Arisaka (2026, A3-BI6), whose by-product is the integer ledger Eq. (3) that Appendix 66 then spends.

The circle, expanded in modes. Make the first claim quantitative. A bulk gauge field on $\mathcal{M}_4 \times S_\theta^1$ decomposes as

$$A_\mu(x, \theta) = \sum_{n \in \mathbb{Z}} A_\mu^{(n)}(x) e^{in\theta}, \quad m_n^2 = \frac{(n + \alpha/2\pi)^2}{R^2}, \quad (79)$$

with R the circle’s radius and α the Wilson-line modulus of Eq. (64). Three readings, each a body claim made technical. The $n = 0$ mode is the four-dimensional gauge field of Eq. (19) — so the boundary’s gauge symmetry is the circle’s zero mode, not an independent postulate. The label n is the winding charge, quantized because $e^{in\theta}$ must be single-valued — so charge quantization is Fourier analysis on a compact space, which is Problem 4’s “labels” in one line. And α shifts the entire tower: a circle-side modulus setting four-dimensional masses, which is the Hosotani mechanism and the mechanism behind Eq. (9)’s electroweak scale.

Gauge invariance, restated as a theorem about readability. On the anatomy the statement “physics is invariant under Eq. (23)” becomes: *the boundary can read functions of W_θ , Eq. (64), and nothing else about the fiber’s connection.* The proof is the decomposition of §63.3: local values of A_θ are shifted by any single-valued $g(\theta)$, while the loop integral is shifted only by $2\pi n$. Elitzur’s theorem is then not a surprise but a corollary — a quantity that no admissible observable depends on cannot acquire an expectation value — and the Higgs mechanism is relabeled honestly: what acquires a value is the readable modulus α , and what the boundary registers is the spectrum Eq. (79) it induces.

The interval, and the geometric origin of the beta function. On the anatomy, μ is not an arbitrary bookkeeping scale but a position: $r = \ln(E_{\text{GUT}}/\mu)$. Motion along the interval carries a warp, and the effective four-dimensional couplings are integrals of the bulk coupling over the traversed region. Differentiating the traversed integral with respect to the endpoint gives a first-order flow in r — which is Eq. (24) with

$$\frac{\partial}{\partial r} = -\mu \frac{\partial}{\partial \mu}, \quad \text{hence} \quad \frac{dg}{dr} = -\beta(g). \quad (80)$$

Two consequences that the four-dimensional formalism cannot state. First, the flow now has *endpoints*: $r = 0$ at the GUT surface and $r = K$ at the descent’s floor, so the total length is a physical quantity ($K = 35$) rather than a range of convenience — this is the content of Problem 6’s dissolution. Second, the Callan–Symanzik statement Eq. (77) that no address is privileged becomes a statement about a coordinate: physics is invariant under *relabeling* positions on I_r , not under translations along it, because the endpoints are fixed.

Anomaly inflow: why the integer lives on the circle. In $2n$ dimensions the anomaly is encoded in a $(2n + 2)$ -form anomaly polynomial I_{2n+2} , related to the boundary anomaly by the descent equations

$$I_{2n+2} = dI_{2n+1}, \quad \delta_{\text{gauge}} I_{2n+1} = dI_{2n}, \quad (81)$$

whose coefficients are fixed by characteristic classes — integrals of curvature forms that are, by the Chern–Weil theorem, *integers* for the compact directions. Two facts follow immediately. The coefficients cannot run, because Eq. (80) is a continuous flow and $\mathbb{Z}$ is discrete (the same argument as §63.3). And their cancellation is a condition on the *bulk*, not a coincidence of the boundary spectrum: the six-dimensional instance is the Green–Schwarz mechanism (Arisaka, 2026, A3-BI6; Green and Schwarz, 1984), whose solution fixes the

coefficient vector and, as a by-product, the integer ledger Eq. (3). The audit of Eq. (25) that a student verifies generation by generation is the four-dimensional shadow of that six-dimensional closure — which is why it holds exactly, and why its by-products are exact too.

65.4 Step 4 — problems and worked solutions

C.1. Derive the compensating transformation of A_μ from the demand that $D_\mu\psi$ transform like ψ .

Solution. Step 1. Require $D_\mu(e^{iq\chi}\psi) = e^{iq\chi}D_\mu\psi$. *Step 2.* Expanding the left side gives $e^{iq\chi}(\partial_\mu + iq\partial_\mu\chi - iqA_\mu/\hbar)\psi$. *Step 3.* Matching requires $A_\mu \rightarrow A_\mu + \hbar\partial_\mu\chi$, which is Eq. (23). *Physics intuition:* the gauge field’s transformation law is not an independent postulate; it is whatever is required to make comparison at a distance possible, which is exactly what a connection is for.

C.2. Compute b_0 for QCD with six flavors and state the sign consequence.

Solution. Step 1. From Eq. (75), $b_0 = 11 - \frac{2}{3}(6) = 7$. *Step 2.* Since $b_0 > 0$, $\beta(g) < 0$, so g decreases as μ increases. *Step 3.* The coupling therefore grows toward low energy, and the perturbative description fails near Λ_{QCD} . *Physics intuition:* asymptotic freedom and confinement are the two ends of one monotone reading along the interval — Appendix 70 picks the story up exactly where Eq. (75) stops being trustworthy.

C.3. Verify both hypercharge sums of Eq. (25) for one Standard-Model generation.

Solution. Step 1. Write every field as a left-handed Weyl fermion — this is essential, since conjugation flips the sign of Y and the cubic sum is not convention-blind. With $Y = 2(Q - T_3)$ the content is Q ($Y = \frac{1}{3}$, $2 \times 3 = 6$ states), u^c ($-\frac{4}{3}$, 3), d^c ($\frac{2}{3}$, 3), L (-1 , 2), e^c (2, 1). *Step 2.* The linear sum — the mixed gravitational anomaly — $6(\frac{1}{3}) + 3(-\frac{4}{3}) + 3(\frac{2}{3}) + 2(-1) + 2 = 2 - 4 + 2 - 2 + 2 = 0$. *Step 3.* The cubic sum — the $U(1)^3$ anomaly — $6(\frac{1}{27}) + 3(-\frac{64}{27}) + 3(\frac{8}{27}) + 2(-1) + 8 = -6 + 6 = 0$. Both cancellations run between quarks and leptons and fail if either is removed. *Physics intuition:* the electron’s charge is tied to the quark’s by a consistency condition, not by a coincidence — which is why hydrogen is neutral to one part in 10^{21} , and why this paper reads the integer as circle-side data.

C.4. A student says: “the interval is just the renormalization group, renamed.” Give the sharpest reply you can.

Solution. Step 1. Concede the overlap: on the four-dimensional boundary the interval’s readings *are* the RG flow, and no equation of the RG is changed. *Step 2.* Identify the difference: the RG is a statement about descriptions at different resolutions, and has no length, no endpoints, and no other physics attached; the interval has a definite extent $K = 35$, endpoints that are physical events (the GUT edge, the lock, the terminus), and a warp factor that is gravity’s (Problems 6, 5, 2). *Step 3.* The distinction is testable: the RG predicts nothing about M_{lock} or N^* ; the interval predicts both. *Physics intuition:* identifying a known flow with a geometric coordinate is only a rename until the geometry says something the flow could not — and a resonance at 3.849 TeV would be exactly that something.

C.5. Why can a gauge symmetry not break, and what does the Higgs mechanism break instead?

Solution. Step 1. By Elitzur’s theorem the expectation value of any gauge-variant quantity vanishes identically, so no local order parameter exists. *Step 2.* What acquires an expectation value is a gauge-*fixed* quantity, or equivalently a gauge-invariant composite; the physical content is the spectrum, not the “broken” symmetry. *Step 3.* On the anatomy the honest statement is a *reading*: the circle’s unreadable pointer settles at a lattice value, and the boundary registers the consequences — masses — rather than the angle. *Physics intuition:* this is why symmetry breaking in this paper is always called symmetry *reading*: nothing breaks, something gets read, and the reading is where the physics is.

Take-away. The two principles that carry all of field theory are the two fibers in disguise: gauge invariance is the circle’s unreadability, renormalization is the interval’s one-way motion, and the anomaly is the first auditing the second. Nothing in the standard formalism changes; what changes is that both principles acquire a referent.

66 The parameter codebook: from the ledger to the laboratory

What this appendix teaches. How the Standard Model’s free parameters are counted, and why the count is what it is; what “measuring a parameter” actually involves once couplings run; why no amount of work inside a quantum field theory can output its own inputs; and then the codebook arithmetic worked end to end, with the numerology discipline stated as a procedure rather than a promise. Pay-off: Problem 4.

Read alongside: [Particle Data Group \(2024\)](#) for the measured values and their conventions; [Cahn \(1996\)](#) for what each parameter does to the world; [Arisaka \(2026, A9-SM\)](#) for the full twenty-eight-entry derivation this appendix samples.

66.1 Step 1 — the standard treatment: counting the parameters

The count, done carefully. Write the Standard-Model Lagrangian and ask how many numbers must be supplied from outside. Three gauge couplings g_s, g, g' . Two Higgs-sector numbers (the mass parameter and the quartic, equivalently v and m_H). Nine charged-fermion masses — three up-type, three down-type, three charged leptons — through their Yukawa couplings. Four quark mixing parameters: three angles and one CP phase in the CKM matrix. One QCD vacuum angle $\bar{\theta}$. That is nineteen. Adding neutrino masses and lepton mixing (three masses, three angles, one Dirac phase, two Majorana phases if the neutrinos are Majorana) brings the total to twenty-eight. Cosmology then adds its own six for Λ CDM.

Why the count is not obvious. Many apparent parameters are removable by field redefinitions. The quark Yukawa matrices have $2 \times 9 = 18$ complex entries, i.e. 36 real numbers, but most are absorbed by rotating the quark fields; what survives is six masses, three angles, and one phase. The counting theorem — parameters equal Lagrangian entries minus the dimension of the field-redefinition group that acts freely — is a genuine and beautiful piece of physics, and it is worth working once (Problem D.1).

What “measured” means. A coupling is not a number until a scale is named. The fine-structure constant is $1/137.036$ in the Thomson limit and $\approx 1/128$ at the Z pole; both are the same parameter read at different addresses via Eq. (24). A quoted parameter is therefore a triple: value, scheme, and scale. Any comparison between a derived closed form and an experimental number must specify all three, and the codebook does.

The counting theorem, worked. The parameter count is not a matter of inspection; it is a theorem, and the proof is worth doing once. Consider the quark Yukawa sector,

$$\mathcal{L}_Y = -\bar{Q}_L Y_u \tilde{\Phi} u_R - \bar{Q}_L Y_d \Phi d_R + \text{h.c.}, \quad (82)$$

with Y_u, Y_d arbitrary complex 3×3 matrices. Naively that is $2 \times 9 = 18$ complex entries, or 36 real parameters. Now count the freedom to redefine fields. In the absence of Eq. (82) the kinetic terms are invariant under

$U(3)^3$ acting on Q_L, u_R, d_R — three unitary matrices, $3 \times 9 = 27$ real parameters. One combination is not free: baryon number, a $U(1)$ acting equally on all three, leaves Eq. (82) invariant and therefore removes nothing. The physical count is

$$36 - (27 - 1) = 10 = \underbrace{6}_{\text{masses}} + \underbrace{3}_{\text{angles}} + \underbrace{1}_{\text{phase}}, \quad (83)$$

which is Problem D.1’s answer arriving from the other direction. *Physics intuition:* a “parameter” is not an entry in a Lagrangian but an entry that survives every relabeling of the fields — and the arithmetic of Eq. (83) is why a third generation was predicted before it was found: with two generations the same count leaves 0 phases, so CP violation in the quark sector would be impossible.

Repeating the count for the full model. Applying the same procedure sector by sector: three gauge couplings; two Higgs-potential parameters; ten from Eq. (83); one $\bar{\theta}$; and in the lepton sector three charged-lepton masses plus, for Majorana neutrinos, three masses, three angles, one Dirac phase, and two Majorana phases (the Majorana mass term breaks the rephasing freedom that would otherwise remove them). The total is $3 + 2 + 10 + 1 + 3 + 9 = 28$. Cosmology adds six for Λ CDM ($\Omega_b h^2, \Omega_c h^2, \theta_s, \tau, A_s, n_s$). A student should do this count personally once; it is the only way to feel how little of the Standard Model is derived.

What a measured coupling actually is. Take α_s . Nobody measures it: one measures, say, the ratio of three-jet to two-jet events at a given collider energy, computes that ratio to some order in perturbation theory as a function of $\alpha_s(\mu)$ in a chosen scheme (almost always $\overline{\text{MS}}$), and inverts. The output is therefore a triple — value, scheme, scale — and quoting it as a bare number is an abbreviation. Running to a common reference by Eq. (20) is what makes different experiments comparable, and *matching* at each quark threshold (adjusting n_f in b_0) is what makes the running continuous.

Physics intuition. Scheme dependence is often mistaken for a defect. It is the opposite: the scheme is a coordinate choice on the space of descriptions, and physical predictions — cross sections, lifetimes — are scheme-independent by Eq. (77). What is *not* arbitrary is that the running exists at all, and that it runs one way.

The two ways a closed form can be compared. Since a parameter is a triple, a derived closed form must specify where it is evaluated. Two conventions appear in this paper and should not be confused. Some entries are anchored at a physical pole — $\hat{\alpha}^{-1}(M_Z) = 2^J = 128$ — and are compared with the running value at that pole. Others are infrared quantities — $\alpha^{-1}(0) = 2^J + N^2 = 137$ — and are compared with the Thomson limit. The difference between them, $N^2 = 9$, is itself a prediction about the amount of running between the two addresses, and it is checkable independently of either endpoint (Problem D.5).

66.2 Step 2 — what the standard treatment leaves unexplained

The framework is silent by construction, and it is worth being precise about why. A quantum field theory is a *map* from (field content, symmetry, parameters) to (predictions). It is internally consistent for essentially any parameter values — the electron could be ten times heavier and the theory would run perfectly well. There is therefore nothing inside the map that could distinguish the actual values, and no amount of ingenuity applied to the map alone will produce them.

Fifty years of attempts to reduce the count each added structure whose own freedom exceeded what it removed: grand unification related three couplings and bought new scales and a proton lifetime now excluded in its simplest form; the minimal supersymmetric extension stabilized the Higgs mass and introduced more

than a hundred soft parameters; the string landscape replaced computation with selection. The honest summary is that the count has *risen* (Problem 4, and Problem 15 for the selection route).

66.3 Step 3 — the two-fiber resolution: labels and addresses

The grammar. The codebook’s claim is that every parameter is a holonomy-class label wearing a descent address: the label is circle-side arithmetic in the ledger integers Eq. (3) and π , exact and unable to run; the address is interval-side, an exponential of depth. Two fonts, one alphabet, and — the falsifiable core — no third species of primitive.

The chain, checked. Eq. (26) runs from the ledger to the laboratory in five lines. Each line’s structure repeats: integer arithmetic setting structure, depth arithmetic setting scale. The reader can check every step with a calculator, and Problem D.2 asks exactly that.

The discipline that makes it more than numerology. Four procedural commitments, stated because they are the difference between a codebook and a coincidence. *Pre-registration*: closed forms are published with named kill conditions and dated instruments *before* the decisive measurements. *One alphabet*: the same five integers serve every entry; each new closed form is a constraint on the same small ledger, not a fresh dip into the integer sea, so the fits grow *harder* with each success rather than easier. *The flag register*: candidate patterns without mechanism (the $4K/8K$ family) are quarantined at flagged grade and never cited as support. *Cross-exposure*: the same integers face colliders, haloscopes, and the microwave sky, with no shared systematics — a conspiracy of coincidences would have to span four orders of magnitude of experimental technique.

The ledger’s internal identities, derived. The five integers of Eq. (3) are not five inputs. Two relations bind them, and both are structural.

The chirality relation $J = 2N + 1$. The flavor alphabet lives on the compact fiber as a lattice of phases. With N_g generations the boundary registers N_g “forward” steps and N_g “backward” steps of the chiral tape, plus the unstepped origin, giving $2N + 1$ distinguishable letters — hence $J = 7$ for $N = 3$. The count is a count of lattice sites, so it is an integer for the same reason winding numbers are.

The closure relation $K = LJ$. The descent’s total depth is the product of the block structure of the unified group ($L = 5$) with the alphabet’s length ($J = 7$): each of the L blocks is traversed once per letter as the reading proceeds, and the descent ends when the tape is exhausted. Hence $K = 35$.

The consequence is the one Problem 6 spends: K is fixed by L and J through closure, and N — hence J — is fixed inside the anomaly audit by the dual-lock condition (Arisaka, 2026, A3-BI6). One chain, no adjustable step, one integer. The dual lock is not a second route to K : it is the equation that selects N , and it holds identically at both of its roots, so it constrains the ledger without determining K twice.

How a two-font formula is built, and how it could fail. Every entry of the codebook has the form

$$X = \underbrace{f(M, N, L, J, K; \pi)}_{\text{circle: exact, cannot run}} \times \underbrace{e^{-cK} \text{ or } M_{\text{lock}}^p}_{\text{interval: an address}}, \quad (84)$$

with f a ratio of integers and powers of π and c, p small rationals. The falsifiable content is the *absence* of a third factor: no fitted coefficient, no continuous parameter, no $O(1)$ fudge. That is what makes each line of Eq. (26) a test rather than a fit — and it is also, precisely, how the scheme could fail. If a measured value required a factor that is neither ledger arithmetic nor a descent depth, Eq. (84) would be violated at that entry, and the codebook’s grammar — not merely one prediction — would be dead.

Which entries can run, and which cannot: a theorem rather than a taste. Because circle-side quantities are homotopy data and the flow Eq. (80) is continuous, no circle-side quantity has a beta function: $\partial_r f = 0$ identically. Interval-side quantities are, by construction, readings at an address and *must* run. This partitions the sheet into two classes with an observable difference: the sharp prediction is that no quantity the codebook calls a label will ever be found to have scale dependence, and no quantity it calls an address will ever be found without it. Spatial and temporal constancy follow by the same argument (a homotopy class has no gradient), which is why Problem 8’s horizon 2 and Problem 15’s “no drawn constant” are the same statement as this paragraph.

Worked: the weak angle as a partition. The weak angle is a ratio of circle-side quantities, hence pure arithmetic:

$$\sin^2 \theta_W = \frac{g'^2}{g^2 + g'^2} = \frac{L^2}{4N^3} = \frac{25}{108} = 0.23148, \quad (85)$$

against the measured 0.23122 at its matching point (+0.11%). Read the closed form structurally: L^2 counts the abelian partition of the unified block, $4N_g^3$ the generation volume with its doubling. Nothing in Eq. (85) is a scale, so — by the theorem above — the anatomy predicts this value is attached to a fixed matching point and does not itself run; the observed running of the *effective* weak mixing angle is the interval dressing the fixed partition, not the partition changing.

66.4 Step 4 — problems and worked solutions

D.1. Derive the count of four physical parameters in the CKM matrix.

Solution. Step 1. A general 3×3 unitary matrix has 9 real parameters: 3 angles and 6 phases. *Step 2.* Rephasing the six quark fields removes six phases, but an overall common phase acts trivially, so only $6 - 1 = 5$ phases can be removed. *Step 3.* Left: 3 angles and $6 - 5 = 1$ phase, hence four parameters, one of them *CP*-violating. *Physics intuition:* the single surviving phase is why three generations are the minimum for *CP* violation in the quark sector — with two generations the same counting leaves zero phases, and Kobayashi and Maskawa’s prediction of a third generation followed from precisely this arithmetic.

D.2. Check the chain of Eq. (26) numerically, and report the deviations.

Solution. Step 1. $M_{\text{lock}} = \frac{1}{2}(1.2209 \times 10^{19})e^{-35} \text{ GeV} = 3.849 \times 10^3 \text{ GeV}$. *Step 2.* $v = 3849 \times (2/5)^3 = 3849 \times 0.064 = 246.3 \text{ GeV}$ against the measured 246.22 GeV: +0.05%. *Step 3.* $\sin^2 \theta_W = 25/108 = 0.23148$ against 0.23122 (+0.11%); $\alpha^{-1}(0) = 128 + 9 = 137$ against 137.036 (−0.03%). *Physics intuition:* the deviations are at the few-parts-in-a-thousand level with *no* adjustable quantity anywhere in the chain — which is the only kind of agreement that can be evidence, because it is the only kind that could have failed.

D.3. A skeptic says the closed forms are numerology. Construct the strongest version of the charge, then answer it.

Solution. Step 1. The strongest version: with five integers, π , e , and the operations of arithmetic, the space of expressions below a given complexity is large enough that hitting a measured number to 0.1% is unremarkable, and no single agreement is evidence. *Step 2.* The answer is not to deny this but to change what is being counted: the claim is not that one expression matched, but that *one small ledger* matched twenty-eight entries plus the cosmological sheet, with the same integers appearing in unrelated sectors — so the effective number of trials is bounded by the ledger, not by the expression space. *Step 3.* And the claim is dated: each closed form carries a named instrument and era (Table 18). *Physics intuition:* numerology never volunteers to die. The procedural difference is publication order — and it is checkable by anyone with the preprint dates.

D.4. Why does the codebook’s status table (Figure 19) show eight entries still Asserted, and why is that not fatal?

Solution. Step 1. The eight are the charged-fermion Yukawas, whose derivation requires the family surface’s overlap integrals — a named open construction. *Step 2.* A framework that claimed all twenty-eight were theorems would be claiming what the parent papers do not, and a reader could not tell which claims to test. *Step 3.* The public grading is what makes the six Derived entries meaningful: they are the ones that can fail cleanly. *Physics intuition:* the value of an honest ledger is not modesty — it is that a partially finished derivation still makes sharp predictions, provided the reader is told exactly which pages are finished.

D.5. The codebook predicts $\alpha^{-1}(0) - \hat{\alpha}^{-1}(M_Z) = N^2 = 9$. Check it against data and say what it tests.

Solution. Step 1. Measured: $\alpha^{-1}(0) = 137.036$ and $\hat{\alpha}^{-1}(M_Z) = 127.93$ in the $\overline{\text{MS}}$ scheme. *Step 2.* The difference is 9.11, against the predicted 9 — an agreement of 1.2%. *Step 3.* What it tests is neither endpoint but the *amount of running* between them, which in the standard framework is a loop computation depending on the whole charged-particle spectrum. *Physics intuition:* this is the most demanding kind of check available to a codebook, because it is insensitive to any single closed form: both endpoints could be wrong in the same direction and the difference would still fail. That it does not fail is the strongest internal evidence that the two-font grammar of Eq. (84) is tracking something.

Take-away. The parameter problem is not hard because the numbers are strange; it is hard because a framework whose parameters are inputs cannot output them. The codebook’s proposal is that the sheet was never a list of constants but a text in two fonts — and the proposal is testable entry by entry, with the finished pages marked.

67 The launch and the descent: inflation, e-folds, and the hierarchy

What this appendix teaches. FRW cosmology from the Einstein equations; the horizon and flatness problems stated quantitatively; slow-roll inflation derived, with the spectral observables computed from the potential; the hierarchy problem as a one-loop estimate; and then the two-fiber reading in which the inflaton is the interval’s coordinate, the e-fold count is a length, and the hierarchy is a depth. Pay-off: Problems 5, 6, and 8.

Read alongside: Baumann (2022), Ch. 2 and 4, for FRW and inflation at exactly this level; Weinberg (2008), Ch. 1 and 10; Kolb and Turner (1990) for the thermal history.

67.1 Step 1 — the standard treatment

The expanding background. For a homogeneous, isotropic universe with scale factor $a(t)$, the Einstein equations reduce to the Friedmann pair

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G_N}{3}\rho - \frac{k}{a^2}, \quad \frac{\ddot{a}}{a} = -\frac{4\pi G_N}{3}(\rho + 3p), \quad (86)$$

with ρ the energy density, p the pressure, and k the spatial curvature. The second equation contains the whole drama of inflation in one sign: acceleration requires $p < -\rho/3$.

The two classic problems. *Horizon:* the comoving particle horizon grows in a decelerating universe, so the $\sim 10^4$ causally independent patches of Eq. (35) should not share a temperature — they do, to 10^{-5} .

Flatness: writing Eq. (86) as $|\Omega - 1| = |k|/(aH)^2$, and noting that $(aH)^{-1}$ grows in both radiation and matter eras, the present near-flatness demands $|\Omega - 1| \lesssim 10^{-60}$ at the Planck epoch.

Slow roll. A scalar φ with potential $V(\varphi)$ has $\rho = \frac{1}{2}\dot{\varphi}^2 + V$ and $p = \frac{1}{2}\dot{\varphi}^2 - V$, so $p \rightarrow -\rho$ when the kinetic term is negligible. The conditions for that are Eq. (27)’s $\epsilon, \eta \ll 1$, and while they hold the stretch accumulates the e-folds of Eq. (28). Both problems are solved if $N \gtrsim 60$: $(aH)^{-1}$ shrinks during inflation, so today’s largest scales were inside one causal patch, and curvature is diluted by e^{-2N} .

The observables. Quantum fluctuations of φ stretched outside the horizon become the primordial perturbations, with scalar and tensor spectra whose tilts are fixed by the potential’s shape at horizon exit:

$$n_s - 1 = -6\epsilon + 2\eta, \quad r_T = 16\epsilon. \quad (87)$$

For the plateau class ($V \rightarrow \text{const}$ at large φ) these collapse to the one-parameter forms of Eq. (31), depending only on N^* , the e-folds between horizon exit of the observed scales and the end of inflation.

The hierarchy, as a one-loop estimate. A scalar’s squared mass receives Eq. (30)’s correction, quadratic in the cutoff. With $\Lambda = M_{\text{Pl}}$ the correction exceeds the measured m_H^2 by $\sim (10^{19}/10^2)^2 = 10^{34}$, so the bare parameter must cancel it to thirty-four digits.

From Einstein’s equations to Eq. (86). Assume homogeneity and isotropy: the metric is $ds^2 = -dt^2 + a^2(t)[dr^2/(1 - kr^2) + r^2 d\Omega^2]$. Computing the Ricci tensor for this metric and inserting a perfect fluid $T^\mu{}_\nu = \text{diag}(-\rho, p, p, p)$, the 00 component of $G_{\mu\nu} = 8\pi G_N T_{\mu\nu}$ gives the first Friedmann equation and the trace gives the second. Their compatibility requires the continuity equation

$$\dot{\rho} + 3H(\rho + p) = 0 \quad \implies \quad \rho \propto a^{-3(1+w)}, \quad w \equiv p/\rho, \quad (88)$$

so radiation ($w = \frac{1}{3}$) dilutes as a^{-4} , matter ($w = 0$) as a^{-3} , and vacuum ($w = -1$) not at all. *Physics intuition:* Eq. (88) is energy conservation with a work term — the universe does $p dV$ against itself — and the reason the vacuum does not dilute is that $w = -1$ makes that work exactly cancel the volume growth. The entire late history is the competition of three power laws, and the “coincidence” of Problem 7 is the observation that the crossover is happening now.

The horizon problem, in numbers. The comoving particle horizon is $\eta = \int_0^t dt'/a(t') = \int_0^a da'/(a'^2 H)$, which for $w > -\frac{1}{3}$ is dominated by late times — so it *grows*, and regions entering it today were never in contact. At last scattering the horizon subtends $\sim 2^\circ$ (Eq. (35)), giving $\sim 10^4$ independent patches, all at the same temperature to 10^{-5} .

Slow roll, derived. For a homogeneous scalar the equation of motion is

$$\ddot{\varphi} + 3H\dot{\varphi} + V'(\varphi) = 0, \quad (89)$$

with $3H\dot{\varphi}$ acting as Hubble friction. Neglecting $\ddot{\varphi}$ and the kinetic energy in Eq. (86) gives the slow-roll system $3H\dot{\varphi} \simeq -V'$ and $H^2 \simeq V/3M_{\text{Pl,red}}^2$. Self-consistency of both approximations is precisely Eq. (27): $\epsilon \ll 1$ keeps the kinetic energy small, $|\eta| \ll 1$ keeps the friction dominant. The e-fold count then follows by the chain rule, $dN = H dt = (H/\dot{\varphi}) d\varphi = -(V/M_{\text{Pl,red}}^2 V') d\varphi$, which integrates to Eq. (28).

Where the spectrum comes from. Quantize the fluctuation $\delta\varphi$ on the quasi-de Sitter background. Each Fourier mode behaves as a harmonic oscillator with a time-dependent mass; deep inside the horizon ($k \gg aH$) it oscillates in its vacuum, and as the horizon shrinks past it ($k = aH$, “horizon exit”) the mode freezes with amplitude $|\delta\varphi_k| \simeq H/\sqrt{2k^3}$. Converting to the curvature perturbation $\mathcal{R} = -H\delta\varphi/\dot{\varphi}$ gives the scalar power spectrum

$$\Delta_{\mathcal{R}}^2(k) = \frac{1}{8\pi^2} \frac{H^2}{M_{\text{Pl,red}}^2} \frac{1}{\epsilon} \Big|_{k=aH}, \quad n_s - 1 \equiv \frac{d \ln \Delta_{\mathcal{R}}^2}{d \ln k} = -6\epsilon + 2\eta, \quad (90)$$

the tilt arising purely because H and ϵ drift slowly between the exits of different modes. The same calculation for the two tensor polarizations gives $\Delta_h^2 = 2H^2/\pi^2 M_{\text{Pl,red}}^2$, whence $r_{\text{T}} = \Delta_h^2/\Delta_{\mathcal{R}}^2 = 16\epsilon$, completing Eq. (87). *Physics intuition.* The sky’s largest structures are the frozen shadows of vacuum fluctuations that happened to be crossing the horizon while the universe was inflating — and the tilt is a clock reading: it measures how much the expansion rate changed between the exit of one scale and the next. That is why a single number, N^* , controls both observables on a plateau.

Reheating, and why N^* is usually a range. After slow roll fails the field oscillates about its minimum and decays, reheating the universe to T_{rh} . Matching the observed scales back through this epoch gives

$$N^* \simeq 62 - \ln \frac{k_*}{a_0 H_0} + \ln \frac{V_*^{1/4}}{10^{16} \text{ GeV}} + \frac{1 - 3w_{\text{rh}}}{3(1 + w_{\text{rh}})} \ln \frac{\rho_{\text{rh}}^{1/4}}{V_*^{1/4}}, \quad (91)$$

so N^* depends on the unknown reheating history — which is why the standard practice is to quote 50–60 and let the data choose. Everything in this appendix’s Step 3 turns on removing that freedom.

67.2 Step 2 — what the standard treatment leaves unexplained

The potential is chosen. Eq. (87) maps a potential to observables, and hundreds of potentials have been written. Nothing in the framework prefers one; the plateau class is favored by data, not derived.

The initial condition is stipulated. Slow roll requires the field to begin high on the plateau, over a region already large enough to inflate. Since inflation cannot be past-eternal (Borde et al., 2003), the question survives its own solution (Problem 5).

The e-fold count is a fit. N^* depends on the reheating history, which is unknown; the standard practice is to quote a range 50–60 and let the data pick. The observables of Eq. (87) are therefore predictions only up to that range.

Naturalness is not a law. The one-loop estimate assumes the cutoff is physical and that no structure intervenes. It told a generation where to look, and the null result at the LHC is its clearest verdict (Problem 6).

67.3 Step 3 — the two-fiber resolution

The inflaton is the interval, and there is only one. The census of Part II forbids the menu: the bulk has exactly one non-compact non-spatial direction, so it has exactly one field of this kind, and the plateau shape is what the boundary law’s anomaly structure permits rather than what fits. The roll happens *once* — Eq. (62) has no inverse — which retires eternal inflation structurally rather than by fiat.

N^* is a length, not a fit. On the anatomy the e-fold count is the traversed portion of a fiber of definite extent, and the cohort derives $N^* = 52.6$ with the reheating match made explicit (Arisaka, 2026, A10-Cosmos). Eq. (31) then reads $n_s = 0.9634$ and $r_{\text{T}} = 0.0038$ as *numbers*, and the tensor value sits an

order of magnitude above the design floors of the coming polarization missions. Grade: derived-conditional (the plateau-class argument and the prompt-crossing lemma are named).

The hierarchy is the interval’s depth. The weak scale is not a small number surviving a large correction but an address: $M_{\text{lock}} = \frac{1}{2}M_{\text{Pl}}e^{-K}$, Eq. (15), with $K = 35$ fixed by the ledger identity $K = LJ$, whose factors the dual-lock anomaly condition fixes upstream (one chain, audited at every step; see Problem 6 for why it is not two). Eq. (30)’s Λ is then not free: the descent supplies its own completion at the lock, and the loop’s reach is priced by the same integer that sets the scale. Nothing cancels; something is deep.

And the three horizons separate. Inflation buys the first agreement of Problem 8 — shared conditions — and only that. The sameness of particle *kinds* is circle-side (classes cannot vary by region), and the sameness of the *choices* made after the stretch is the groove’s (a quantized dial with a unique winner). The standard treatment conflates all three because it has one mechanism; the anatomy separates them because it has two fibers and a selection theorem.

Why the interval’s coordinate *is* the inflaton. The identification is not an analogy. On $\mathcal{M}_4 \times I_r \times S_\theta^1$ the position of the boundary along I_r is a four-dimensional scalar field: writing the induced metric with a warp $e^{-2A(r)}$, the fluctuation of the boundary’s location $r(x)$ has a canonically normalized kinetic term and a potential inherited from the warp,

$$\mathcal{L}_{\text{eff}} = \frac{1}{2}(\partial_\mu \varphi)^2 - V(\varphi), \quad \varphi \propto M_{\text{Pl,red}} r, \quad (92)$$

— one field, because there is one such coordinate. This is the census statement of Part II made technical: the menu of inflaton candidates is not narrowed by taste but *closed* by the bulk’s dimension count. The same identification fixes the shape’s class: the potential is the warp, and the warp is determined by the boundary law’s anomaly structure rather than chosen, giving the plateau family whose small- ϵ region is Eq. (31)’s parent.

Why the roll happens once. In Eq. (92) the field is a *position*, and positions on I_r compose by Eq. (65): the physical transport has no inverse. An eternally inflating patch would require the coordinate to be re-randomized upward somewhere, which is precisely the operation the semigroup does not contain. The structural retirement of eternal inflation — and hence of the measure problem that Problem 15 inherits — is therefore a theorem about the fiber’s algebra, not a preference about initial conditions.

N^* as a length, computed. Because I_r has endpoints, the quantity that Eq. (91) leaves free is determined. The descent’s full length is $K = 35$ in the ledger’s units, and the observable window’s position within it is fixed by two things the cohort computes rather than assumes: the reheating temperature (from the warp’s exit behavior) and the g_* counting at that temperature. Carrying those through (Arisaka, 2026, A10-Cosmos) gives $N^* = 52.6$, and hence

$$n_s = 1 - \frac{2}{52.6} = 0.9634, \quad r_{\text{T}} = \frac{12}{52.6^2} = 0.0038, \quad (93)$$

with no free parameter left anywhere in the chain. Grade: derived-conditional — the plateau-class argument and the prompt-crossing lemma are the named conditions, and both are stated in the parent paper.

Physics intuition. In the standard treatment N^* is an uncertainty; here it is a *measurement of the fiber’s geometry*. The two numbers in Eq. (93) are therefore not two predictions but one: a single length, read twice. Falsifying either falsifies the length.

The hierarchy as an integrated warp. The same warp that supplies Eq. (92)’s potential supplies the scale hierarchy. A four-dimensional mass parameter located at position r along the interval is measured on the boundary as

$$m_{\text{eff}}(r) = m_0 e^{-r}, \quad \text{so} \quad M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K} \quad \text{at} \quad r = K = 35, \quad (94)$$

which is Eq. (15). Two remarks make this more than relabeling. First, the exponent is not tunable: it is a ledger integer, fixed twice over (§66.3). Second, the loop correction of Eq. (30) is cut off not at an arbitrary Λ but at the address where the descent supplies its own completion — so the correction is bounded by the same e^{-K} that sets the scale, and the ratio $\delta m_H^2/m_H^2$ is $O(1)$ rather than 10^{32} . There is no cancellation anywhere in this argument, which is exactly why it does not require one.

67.4 Step 4 — problems and worked solutions

E.1. Show that $|\Omega - 1|$ decreases during inflation and increases afterwards.

Solution. *Step 1.* From Eq. (86), $\Omega - 1 = k/(aH)^2$. *Step 2.* During inflation aH grows nearly exponentially, so $|\Omega - 1| \propto e^{-2N}$. *Step 3.* In radiation and matter eras aH falls, so $|\Omega - 1|$ grows — which is why the present near-flatness requires either an enormous initial tuning or an inflationary episode. *Physics intuition:* flatness is not a coincidence to be explained once but an instability to be outrun; the stretch buys enough margin that sixty e-folds of later growth still leave the universe flat to a per-cent.

E.2. Derive the plateau limits $n_s = 1 - 2/N^*$ and $r_T = 12/N^{*2}$.

Solution. *Step 1.* For the plateau class $\epsilon \simeq 3/(4N^2)$ and $\eta \simeq -1/N$ at N e-folds before the end. *Step 2.* Substituting into Eq. (87): $n_s - 1 = -6(3/4N^2) + 2(-1/N) \simeq -2/N$ to leading order. *Step 3.* And $r_T = 16(3/4N^2) = 12/N^2$. *Physics intuition:* on a plateau the only scale left is “how far from the end,” so both observables must be functions of N alone — which is why a derived N^* converts two measured numbers into two tests at once.

E.3. With $N^* = 52.6$, evaluate both.

Solution. *Step 1.* $n_s = 1 - 2/52.6 = 0.96198$. *Step 2.* $r_T = 12/52.6^2 = 0.004337$. *Step 3.* Compare $n_s^{\text{obs}} = 0.9649 \pm 0.0042$ (pull -0.7) and $r_T < 0.036$ (consistent; the Simons Observatory and LiteBIRD reach toward $\sigma(r) \simeq 10^{-3}$, several times below 0.0038). *Physics intuition:* the tensor number is the sharpest cosmological kill condition in this paper — a null at the design floors removes the derived launch, and a detection near 0.004 would be a photograph of the interval’s first traverse.

E.4. Estimate the fine-tuning of Eq. (30) and restate it as a depth.

Solution. *Step 1.* With $y_t \simeq 1$ and $\Lambda = M_{\text{Pl}}$, $|\delta m_H^2| \sim (3/8\pi^2)(1.2 \times 10^{19})^2 \approx 5 \times 10^{36} \text{ GeV}^2$. *Step 2.* With $m_H^2 = (125)^2 \approx 1.6 \times 10^4 \text{ GeV}^2$, the ratio is $\sim 3 \times 10^{32}$ — the famous thirty-plus digits. *Step 3.* Written as a depth instead: $\ln(M_{\text{Pl}}/2M_{\text{lock}}) = 35$, a single integer. *Physics intuition:* the same fact is “impossible” in one language and “ $K = 35$ ” in the other; the choice of language is exactly what this paper is arguing about, and the arbitration is whether anything sits at 3.849 TeV.

Take-away. Inflation’s mechanism is inherited whole; what the anatomy supplies is the census that forbids the menu, the length that fixes N^* , and the reading in which the hierarchy is an address rather than a cancellation. All three are exposed: the tensor floor, the lock, and the entrance.

68 The dark sector: misalignment, the Kaxion, and the vacuum

What this appendix teaches. The axion from the Peccei–Quinn mechanism, and the misalignment relic computed; the haloscope detection principle; the Λ CDM inventory and how its shares are measured; the cosmological constant problem stated in its full severity; and then the two-fiber reading in which the dark sector is the pair of non-spatial coordinates in three states of motion. Pay-off: Problem 7.

Read alongside: Kolb and Turner (1990), Ch. 10, for relic abundances; Preskill, Wise, and Wilczek (1983) for the misalignment calculation in the original; Weinberg (1989) for the vacuum-energy problem as it stood before the discovery.

68.1 Step 1 — the standard treatment

Why an axion exists, in the standard story. QCD permits the CP -violating term $\bar{\theta} (g_s^2/32\pi^2) G\tilde{G}$, and the neutron EDM bounds $|\bar{\theta}| \lesssim 10^{-10}$ (Abel et al., 2020). Peccei and Quinn promoted $\bar{\theta}$ to a dynamical field whose potential — generated by QCD instantons — is minimized at zero, so the angle relaxes rather than being tuned. The pseudo-Goldstone boson of the broken symmetry is the axion, with mass and decay constant related by

$$m_a \simeq \frac{\sqrt{\chi_{\text{QCD}}}}{f_a}, \quad \chi_{\text{QCD}} \approx (75.5 \text{ MeV})^4, \quad (95)$$

χ_{QCD} being the QCD topological susceptibility. A larger decay constant means a lighter, more weakly coupled axion.

The misalignment relic. Before QCD becomes strong the axion potential is negligible and the field sits at an arbitrary initial angle θ_i . When the Hubble rate falls below the axion mass, $3H \simeq m_a$, the field begins to oscillate; the oscillation energy redshifts like matter, $\rho_a \propto a^{-3}$, and survives as cold dark matter. The relic density scales as

$$\Omega_a h^2 \propto \theta_i^2 \left(\frac{f_a}{10^{12} \text{ GeV}} \right)^{7/6}, \quad (96)$$

the exponent 7/6 coming from the temperature dependence of χ_{QCD} near the QCD crossover (the prefactor is computed in the references, and carries the largest theory uncertainty in the field).

Haloscopes. A galactic-halo axion converts to a microwave photon in a strong magnetic field, resonantly if the cavity is tuned to $\nu = m_a c^2/h$. The signal power scales as $B^2 V Q$, and the search proceeds by scanning frequency — which is why the axion’s *mass* is the crucial unknown: it sets where to look.

The inventory, and the vacuum. The measured shares are $\Omega_m \simeq 0.315$, $\Omega_b \simeq 0.049$, $\Omega_\Lambda \simeq 0.685$ (Planck Collaboration, 2020). The last is the problem: a naive estimate of the vacuum energy from zero-point modes up to the Planck scale exceeds the measured value by $\sim 10^{120}$, and no symmetry is known that sets it to the observed small non-zero number (Weinberg, 1989).

The instanton potential, and where Eq. (95) comes from. QCD’s vacuum energy depends on the effective angle $\bar{\theta}$ through the topological susceptibility,

$$V(\bar{\theta}) = -\chi_{\text{QCD}} \cos \bar{\theta} \implies m_a^2 = \left. \frac{\partial^2 V}{\partial a^2} \right|_{\min} = \frac{\chi_{\text{QCD}}}{f_a^2}, \quad (97)$$

where $a = f_a \bar{\theta}$ is the canonically normalized field. The susceptibility itself is computable in chiral perturbation theory: $\chi_{\text{QCD}} = m_u m_d f_\pi^2 m_\pi^2 / (m_u + m_d)^2$, giving $\chi^{1/4} \approx 75.5$ MeV. *Physics intuition:* the axion's mass is not a free parameter of the axion — it is QCD's own vacuum stiffness divided by the scale at which the field lives. A larger f_a means a flatter potential and a lighter, more weakly coupled particle; the entire experimental landscape is that one inverse proportionality.

The relic density, derived rather than quoted. Before QCD confines, $\chi(T)$ is suppressed and the field is frozen by Hubble friction at its initial value θ_i . Oscillation begins when

$$3H(T_{\text{osc}}) = m_a(T_{\text{osc}}), \quad (98)$$

after which the energy density $\rho_a \simeq \frac{1}{2} m_a^2 f_a^2 \theta_i^2$ redshifts as a^{-3} (Problem F.2), while the comoving number density n_a/s is conserved. Tracking n_a/s from T_{osc} to today and using the measured entropy density gives Eq. (96); the exponent 7/6 comes from the temperature dependence $\chi(T) \propto T^{-n}$ with $n \approx 8$ near the crossover, entering through T_{osc} 's dependence on f_a . The largest theory uncertainty in the whole subject sits in that n , which is why the prefactor is quoted with a factor-of-two band in the literature.

The haloscope, quantitatively. In a magnetic field the axion mixes with the photon through $\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$, so a halo axion of mass m_a converts resonantly in a cavity tuned to $\nu = m_a c^2/h$. The signal power is

$$P_{\text{sig}} = g_{a\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L, \quad (99)$$

with B_0 the field, V the volume, C a mode-overlap factor, and Q_L the loaded quality factor. With $\rho_a \simeq 0.45$ GeV/cm³ this is of order 10^{-23} W — which is why haloscopes are among the most sensitive radio receivers ever built, and why the scan rate, not the sensitivity, is the binding constraint.

How the inventory is measured. The shares of Eq. (10) are not weighed directly. Ω_b comes from the odd/even acoustic peak ratio in the CMB (baryons load the photon-baryon fluid and enhance compressions); Ω_m from the peak positions and the matter-radiation equality scale; Ω_Λ from flatness plus the distance–redshift relation of supernovae and BAO. Three different physical effects, three independent handles — which is why the inventory is now known to per-cent precision and why any derived closed form for it is sharply testable.

The vacuum problem, stated at full strength. Summing zero-point energies of a field up to a cutoff gives $\rho_{\text{vac}} \sim \Lambda^4/16\pi^2$. With $\Lambda = M_{\text{Pl}}$ this exceeds the measured $\rho_\Lambda \simeq (2.24 \text{ meV})^4$ by $\sim 10^{120}$. Even with Λ at the electroweak scale the discrepancy is 10^{55} . No symmetry is known that sets the result to zero and allows a small non-zero remainder — supersymmetry would give exact cancellation if unbroken, and its breaking reintroduces a contribution far too large.

68.2 Step 2 — what the standard treatment leaves unexplained

The mass is unpredicted. Eq. (95) relates m_a to f_a , and f_a is a free scale spanning many decades. Experiments therefore scan rather than test, and a null result over a decade of frequency excludes parameter space without indicating where to look next.

The initial angle is free. Eq. (96) depends on θ_i^2 , drawn at random in the standard picture — which also predicts isocurvature fluctuations and, in some scenarios, topological defects.

The dark-matter identity is unconstrained by the gravitational evidence. The allowed mass range for a dark-matter particle spans some ninety orders of magnitude; the evidence is entirely gravitational and says almost nothing about what the particle is.

The vacuum is anti-explained. The framework's own estimate is wrong by 10^{120} , and the coincidence that $\rho_\Lambda \sim \rho_m$ now has no mechanism (Problem 7).

68.3 Step 3 — the two-fiber resolution

One circle, one axion — with numbers. The census forbids the menu here as it did for the inflaton: one compact non-spatial direction, hence one field of this kind. The cohort's Kaxion has its decay constant fixed by the cap loading, $f_K = f_{\text{bulk}}/\Xi_{\text{cap}}$ with $\Xi_{\text{cap}} = K + N + L = 43$ (benchmark; the one open integer). Inverting Eq. (95) at the cohort's $m_K = 8.1 \mu\text{eV}$ with $\chi_{\text{QCD}}^{1/4} = 76 \text{ MeV}$ gives $f_K \simeq 7.1 \times 10^{11} \text{ GeV}$, hence a bulk scale $f_{\text{bulk}} = \Xi_{\text{cap}} f_K \simeq 3.1 \times 10^{13} \text{ GeV}$ — and a reader who wants to check the chain end to end should run those two numbers through Eq. (95) rather than take the result on trust. Eq. (95) then returns definite laboratory numbers, Eq. (32): $m_K \simeq 8.1 \mu\text{eV}$ and a line at 1.95 GHz, inside a cap window whose lowest rung is the ledger integer itself, $\Xi_{\text{cap}} = K$. The experiment changes character: one identifies by the circle's structure — the discrete cap window, and the count that puts one line in it — rather than merely scanning for power.

The angle is pinned, not drawn. Where the standard picture draws θ_i at random, the anatomy's reflection-symmetric dressing freezes the compact angle during the roll, patch-uniformly. That is a conditional claim (the pinning is named), and it is the cleanest null in cosmology: zero axion-sector isocurvature and no defects. An isocurvature detection kills it.

The trio, sorted. Inflation is the interval's coordinate rolling once; the Kaxion is the circle's coordinate still ringing; dark energy is both at rest — the terminus. The shares are fiber-volume ratios (the Hopf reading, Eq. (33)), giving Eq. (10)'s $\Omega_m = 1/\pi$, $\Omega_b = 1/2\pi^2$, $\Omega_\Lambda = 1 - 1/\pi$ against measured 0.315, 0.049, 0.685. The vacuum's *scale* is the lock-scale seesaw $m_\Lambda = M_{\text{lock}}^2/M_{\text{Pl,red}} \simeq 6.1 \text{ meV}$ — the depth doubled — with one named, bounded, uncomputed coefficient (ζ_Λ) and the 8K face carried at flagged grade and never spent.

Two compact parents, one light eigenstate. The existence claim is a mixing computation. The compact sector carries two angular directions with mass-squared matrix

$$\mathcal{M}^2 = \begin{pmatrix} \mu_1^2 & \delta^2 \\ \delta^2 & \mu_2^2 \end{pmatrix}, \quad \lambda_{\pm} = \frac{1}{2} \left[\mu_1^2 + \mu_2^2 \pm \sqrt{(\mu_1^2 - \mu_2^2)^2 + 4\delta^4} \right], \quad (100)$$

and when the off-diagonal entry approaches the geometric mean of the diagonals the lighter eigenvalue is driven far below either — the same algebra as a seesaw. The program's compact sector delivers exactly this configuration, so *one* light pseudoscalar exists and its lightness is structural rather than tuned. The census then forbids a second: there is one compact non-spatial fiber, hence one tower of angular moduli, hence one such eigenstate. This is why the anatomy cannot accommodate an axion *zoo* — and why a second, unrelated axion-like detection would be a serious problem for it.

The decay constant, fixed. What remains is the scale. The bulk's natural decay constant is divided by the cap loading,

$$f_K = \frac{f_{\text{bulk}}}{\Xi_{\text{cap}}}, \quad \Xi_{\text{cap}} = K + N + L = 35 + 3 + 5 = 43, \quad (101)$$

the three terms counting the descent's depth, the generation multiplicity, and the block structure — the loading the compact sector must carry. Substituting into Eq. (97) returns Eq. (32): $m_K \simeq 8.1 \mu\text{eV}$ and a line at 1.95 GHz. The honest note, carried everywhere in this paper: $\Xi_{\text{cap}} = 43$ is a *benchmark*, the one

open integer of Arisaka (2026, C1-Kaxion), and the associated window is 1.59–2.13 GHz rather than a single frequency.

The count, and what it replaced. Earlier revisions of this appendix printed a second signature here: a companion line split from the principal one by the descent’s depth, $\Delta\nu/\nu = 1/K = 1/35$, i.e. 56 MHz at 1.95 GHz. Arisaka (2026, C1-Kaxion) has withdrawn it. The registered mode analysis leaves one light angle; the would-be partner is the longitudinal mode of the terminated baryonic vector, at $\sim 1.7 \times 10^{13}$ GeV, and no haloscope reaches it. What the compact structure now says about the spectrum is a *count*:

$$\#\{\text{light QCD-coupled lines in } [1.59, 2.13] \text{ GHz}\} = 1, \quad (102)$$

and the ledger integer enters the laboratory not as a splitting but as the ladder’s lowest admissible rung, $\Xi_{\text{cap}} = K = 35$, which places the window’s lower edge at $1.95 \times 35/43 = 1.59$ GHz.

That is a real loss and it is worth stating as one. The withdrawn ratio was *scale-free* — independent of Ξ_{cap} , of f_{bulk} and of the halo density, so it survived every uncertainty that afflicts Eq. (99)’s normalization. The window does not: it moves with the calibration, and the count is derived-conditional rather than theorem-level. A haloscope that resolved two lines at the old spacing would have measured a ledger integer directly; a haloscope that finds one line alone across a swept window confirms a count, which is less.

The inventory as fiber volumes. The shares are ratios of the two fibers’ volumes in the Hopf presentation of the bulk’s compact structure (Eq. (33)). Taking the circle’s one-dimensional volume against the three-sphere’s,

$$\frac{\text{Vol}(S^1)}{\text{Vol}(S^3)} = \frac{2\pi}{2\pi^2} = \frac{1}{\pi} \implies \Omega_m = \frac{1}{\pi} = 0.3183, \quad \Omega_b = \frac{1}{2\pi^2} = 0.0507, \quad (103)$$

against measured 0.3153 ± 0.0073 and 0.0493 , with $\Omega_\Lambda = 1 - 1/\pi = 0.6817$ against 0.6847 ± 0.0073 . The content is that the inventory is a *geometric* ratio, not a dynamical outcome: it is fixed by which fibers exist, and so cannot drift, which is the same protection statement as §66.3’s theorem.

The vacuum’s scale, and the honest residue. The terminus energy is the lock scale seesawed against the Planck scale,

$$m_\Lambda = \frac{M_{\text{lock}}^2}{M_{\text{Pl,red}}} = \frac{(3849 \text{ GeV})^2}{2.435 \times 10^{18} \text{ GeV}} = 6.1 \text{ meV}, \quad (104)$$

against $\rho_\Lambda^{1/4} = 2.24 \text{ meV}$ — a ratio $\zeta_\Lambda^{1/4} = 0.37$, where ζ_Λ is the *drainage factor*: named, bounded, and *uncomputed*. In e-fold form Eq. (104) is e^{-2K} — the descent’s depth doubled — and the observation that the vacuum hierarchy’s 120 orders equal $8K$ to about one percent is carried at flagged grade and used nowhere. What the anatomy claims here is therefore narrower and sharper than a solution: the *share* is derived, the *scale* arrives from an already-derived TeV address with no new dial, and one coefficient remains a work order.

68.4 Step 4 — problems and worked solutions

F.1. From Eq. (95), compute m_a for $f_a = 10^{12}$ GeV and convert to a haloscope frequency.

Solution. *Step 1.* $m_a \simeq (75.5 \times 10^{-3} \text{ GeV})^2 / (10^{12} \text{ GeV}) = 5.7 \times 10^{-15} \text{ GeV} = 5.7 \mu\text{eV}$. *Step 2.* The frequency is $\nu = m_a c^2 / h = 5.7 \times 10^{-6} \text{ eV} \times 2.418 \times 10^{14} \text{ Hz/eV} = 1.38 \text{ GHz}$. *Step 3.* For the cohort’s $8.1 \mu\text{eV}$ the same conversion gives 1.96 GHz. *Physics intuition:* the microwave band is not a coincidence of engineering — it is

where the QCD scale divided by a grand-unified-scale decay constant lands, which is why cavity haloscopes are the right instrument at all.

F.2. Show that coherent oscillation energy redshifts like matter.

Solution. Step 1. For $\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$ with $m \gg H$, write $\phi = A(t)\cos(mt)$. *Step 2.* Averaging over oscillations, $\rho = \frac{1}{2}m^2A^2$ and the damping term gives $\dot{\rho} = -3H\rho$. *Step 3.* Hence $\rho \propto a^{-3}$: pressureless matter. *Physics intuition:* a field oscillating fast compared to the expansion is indistinguishable, gravitationally, from a gas of cold particles of mass m — which is how a wave becomes “dark matter” without anything particle-like ever being produced.

F.3. Why does the discrete window matter more than the line itself — and what did the framework lose when the doublet was withdrawn?

Solution. Step 1. A single line at a predicted frequency is a strong but reproducible-by-accident result: many models can be tuned to a frequency. *Step 2.* Earlier revisions answered with a *splitting* fixed at $\Delta\nu/\nu = 1/K$: scale-free, so unabsorbable by recalibrating f_a , and a direct test of the ledger integer. Arizaka (2026, C1-Kaxion) has withdrawn it — one light angle survives the mode analysis — so that answer is gone. *Step 3.* What remains is a *list*: seven admissible frequencies and no eighth, with the lowest rung at $\Xi_{\text{cap}} = K$ itself, and a *count*: one line in that list and no second. A measurement between two rungs, or a second light line inside the window, is unabsorbable in the same way the splitting was. *Step 4.* But the list moves with the calibration where the splitting did not, and the count is graded derived-conditional where the splitting was theorem-level, so the framework is answering the same question with less. *Physics intuition:* detection experiments answer “is something there?”; identification experiments answer “is it *this*?” — and only the second kind can discriminate a geometry. The framework still has an identification experiment. It has a cheaper one than it used to claim and a weaker one than it used to have.

F.4. Restate the cosmological constant problem in the two-fiber language and say precisely what remains open.

Solution. Step 1. The *share* is geometric: $\Omega_\Lambda = 1 - 1/\pi$, a fiber-volume ratio, derived. *Step 2.* The *scale* is the interval’s depth doubled, $m_\Lambda = M_{\text{lock}}^2/M_{\text{Pl,red}}$, which reproduces the meV scale with no new dial — but with one open coefficient ζ_Λ , named and bounded. *Step 3.* What remains open is therefore not “why is it small” but “compute ζ_Λ ” — a narrower and more answerable question, plus the flagged 8K observation that is never used as support. *Physics intuition:* progress here looks like repricing rather than solving, and the paper’s discipline is to say so: a problem converted into a computation is not the same as a problem closed.

Take-away. The dark sector, on this reading, is not a zoo awaiting a discovery but the two hidden coordinates in their three possible states of motion — rolling, ringing, at rest. Every one of the three is exposed: the tensor floor, the haloscope window with its count, and the isocurvature null.

69 Discrete symmetries, *CPT*, and the matter excess

What this appendix teaches. *C*, *P*, and *T* defined as operators, with *T*’s antiunitarity derived rather than asserted; the *CPT* theorem’s three hypotheses and why it is a theorem at all; the CKM phase and the Jarlskog invariant; Sakharov’s three conditions; sphalerons and why they conserve $B - L$; leptogenesis; and then the two-fiber reading in which the three operations are three orientation reversals and the excess is a toll. Pay-off: Problems 9 and 10–11.

Read alongside: Weinberg (1995), Ch. 2 and 5, for the discrete operators and the *CPT* theorem; Peskin and Schroeder (1995), Ch. 3, for *C*, *P*, *T* on Dirac fields; Kuzmin et al. (1985) for the sphaleron rate; Fukugita and Yanagida (1986) for leptogenesis in the original.

69.1 Step 1 — the standard treatment

The three operators. On a Dirac field, parity acts as $P\psi(t, \vec{x})P^{-1} = \gamma^0\psi(t, -\vec{x})$; charge conjugation as $C\psi C^{-1} = i\gamma^2\psi^*$, exchanging particle and antiparticle; and time reversal as $T\psi(t, \vec{x})T^{-1} = \gamma^1\gamma^3\psi(-t, \vec{x})$, with T *antiunitary*. The antiunitarity is not a convention: from $[x, p] = i\hbar$ and $TxT^{-1} = x$, $TpT^{-1} = -p$, one gets $T(i\hbar)T^{-1} = -i\hbar$, so T must conjugate complex numbers (Problem G.1).

The CPT theorem. Any local, Lorentz-invariant quantum field theory with a positive-energy spectrum and the usual spin–statistics connection is invariant under the product CPT . Two of its consequences are exact and heavily tested: a particle and its antiparticle have identical mass and lifetime; and no laboratory has ever seen a violation.

CP violation and the Jarlskog invariant. With three generations, the CKM matrix retains one physical phase (Problem D.1). All CP -violating effects in the quark sector are proportional to the single rephasing-invariant combination

$$J_{CP} = \text{Im}(V_{ud}V_{cs}V_{us}^*V_{cd}^*) \approx 3 \times 10^{-5}, \quad (105)$$

and J_{CP} vanishes if any two quark masses of the same charge are degenerate. This is the measured CP violation — and it is famously too small for cosmology. *A note on notation:* the symbol J is reserved throughout this paper for the ledger integer $J = 2N + 1 = 7$, so the Jarlskog invariant is written J_{CP} here and the Regge spin $\mathcal{J}$ in Appendix H. The clash is standard in the literature and worth naming once rather than letting a reader meet $J = 7$ and $J \approx 3 \times 10^{-5}$ on facing pages.

Sakharov, sphalerons, leptogenesis. A baryon asymmetry requires baryon-number violation, C and CP violation, and departure from equilibrium. The Standard Model supplies all three in principle: $B + L$ is violated non-perturbatively by sphalerons (Kuzmin et al., 1985) while $B - L$ is exactly conserved; CP violation comes from Eq. (105); and the electroweak transition could in principle be out of equilibrium. Quantitatively it fails: the quark phase delivers an asymmetry at least ten orders of magnitude too small (Gavela et al., 1994). Leptogenesis moves the origin to heavy right-handed neutrinos whose out-of-equilibrium decays create a lepton asymmetry, which sphalerons then partially convert to baryons — with the standard conversion factor $B = (28/79)(B - L)$ for Standard-Model content (Kuzmin et al., 1985).

The bilinears, tabulated. The fastest way to see what C , P , T do is to act on the fermion bilinears, since every interaction in the Standard Model is built from them. Writing $\bar{\psi}\Gamma\psi$ for the five Dirac structures (Table 23). Two lessons. A vector interaction ($\bar{\psi}\gamma^\mu\psi A_\mu$) is P - and C -even, so electromagnetism and QCD respect both. An interaction mixing vector and axial ($V - A$, as in the weak current) cannot be: the two pieces have opposite P , so any theory that uses their difference violates parity maximally — which is what Wu et al. (1957) measured. *Physics intuition:* parity violation is not a small effect that had to be searched for carefully; it is total, and it was missed for a quarter-century only because nobody had looked in the one sector where the world distinguishes left from right.

Why CPT is a theorem, in outline. The proof rests on three hypotheses: Lorentz invariance, locality (fields at spacelike separation commute or anticommute), and a spectrum bounded below. The mechanism is analytic continuation: correlation functions of a local field theory extend to complex Lorentz transformations, and the element $-\mathbb{K}$ of the complexified group — which reverses all four coordinates — is connected to the

Table 23: C , P , T and CPT acting on the five Dirac bilinears, which is the fastest way to see what the three operations do, since every Standard Model interaction is built from them. The columns are the scalar, pseudoscalar, vector, axial-vector and tensor structures; each entry is the sign the operation returns, with the spatial components noted where they differ from the time component. The last row is the product, and it is the one that matters for Problem 9: CPT returns +1 on the scalar and the pseudoscalar, -1 on the vector and the axial-vector, and +1 on the tensor.

	$\bar{\psi}\psi$	$\bar{\psi}i\gamma^5\psi$	$\bar{\psi}\gamma^\mu\psi$	$\bar{\psi}\gamma^\mu\gamma^5\psi$	$\bar{\psi}\sigma^{\mu\nu}\psi$
P	+1	-1	+1 (spatial -)	-1 (spatial +)	+1 (mixed)
C	+1	+1	-1	+1	-1
T	+1	-1	+1 (spatial -)	+1 (spatial -)	-1
CPT	+1	+1	-1	-1	+1

identity in the complexified group even though it is not in the real one. Implementing that element on the Hilbert space requires an antiunitary operator, and it acts precisely as CPT .

Physics intuition. CPT is protected not by a dynamical mechanism but by the *shape of the symmetry group*, once the theory is local and the energies are positive. That is why no model-building can violate it without abandoning one of those three hypotheses — and why an observed violation would be far more damaging to physics than the discovery of parity violation was.

The CKM matrix, parametrized. In the standard parametrization

$$V_{\text{CKM}} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}, \quad (106)$$

with $s_{ij} = \sin \theta_{ij}$. The measured hierarchy is striking: $s_{12} \approx 0.22$, $s_{23} \approx 0.042$, $s_{13} \approx 0.0037$, with $\delta \approx 1.14$ rad. The Jarlskog invariant of Eq. (105) evaluates to $J_{CP} = c_{12}c_{23}c_{13}^2 s_{12}s_{23}s_{13} \sin \delta \approx 3 \times 10^{-5}$ — small not because the phase is small (it is of order one) but because the mixing angles are.

Sphalerons, quantitatively. The electroweak vacuum has a periodic structure labeled by Chern–Simons number, and the barrier between adjacent vacua has height

$$E_{\text{sph}} \simeq \frac{4\pi v}{g} B(\lambda/g^2) \approx 9 \text{ TeV}, \quad (107)$$

with B a slowly varying function of order unity. Below the electroweak crossover the transition rate is Boltzmann-suppressed by $e^{-E_{\text{sph}}/T}$ and switches off rapidly; above it, the rate per unit volume is unsuppressed, $\Gamma/V \sim \alpha_W^5 T^4$, and $B + L$ is efficiently violated. Each transition changes B and L by $\Delta B = \Delta L = N_g = 3$ — one unit per generation — so $B - L$ is untouched (Problem G.4).

Leptogenesis, assembled. A heavy right-handed neutrino N_1 of mass M_1 decays to ℓH and $\bar{\ell} H^\dagger$ with a CP asymmetry $\epsilon_1 = [\Gamma(N_1 \rightarrow \ell H) - \Gamma(N_1 \rightarrow \bar{\ell} H^\dagger)]/\Gamma_{\text{tot}}$ generated by interference between tree and one-loop diagrams. With a washout efficiency κ and dilution by the effective degrees of freedom g_* , the resulting baryon asymmetry is

$$\eta_B \simeq 7.04 \times \frac{28}{79} \times \frac{\epsilon_1 \kappa}{g_*}, \quad (108)$$

where 7.04 converts the entropy-normalized asymmetry to the photon-normalized one and 28/79 is the sphaleron reprocessing factor for Standard-Model content. Every factor except $\epsilon_1\kappa$ is standard and computed; the mechanism's whole freedom sits in that one product.

69.2 Step 2 — what the standard treatment leaves unexplained

The pattern is accommodated, not produced. Parity violation is written in by assigning left- and right-handed fields to different representations; the CP phase is a measured input; and $\bar{\theta}$ is a free number that experiment says is zero to ten orders. Each is a dial set to match the world.

CPT 's exactness is proved from assumptions. The theorem tells us the three operations are linked; it does not say why the geometry offers exactly three, nor why the joint operation should be the protected one.

The excess is fitted. Leptogenesis is a mechanism with free masses and phases at energies no experiment reaches. Any observed η_B can be accommodated, which means the observed value has never been predicted (Problems 10–11).

69.3 Step 3 — the two-fiber resolution

Three operations because there are three orientations. The bulk offers exactly three independent senses to reverse: the circle's winding, the stage's handedness, and the clock's direction, Eq. (36). C , P , T are those reversals, so the census of discrete symmetries is a census of geometry — and the count is three because the anatomy has three orientable structures, not because three operators happened to be useful. CPT is the total reversal, an isometry of the whole, hence exact; each single reversal fails wherever a structure fixes its sense — the chiral flavor alphabet fixes the circle's, the runtime fixes the clock's.

The alphabet, audited. The flavor lattice's phases are exact lattice values rather than fitted numbers: the quark phase is a *bystander* (real chirality, negligible throughput), the Dirac neutrino phase a *spectator* at the derived $\delta_{\text{PMNS}} = \pi + 2\arcsin(1/7) = 196.4^\circ$, $\alpha_{21} = 0$ *inert*, and $\alpha_{31} = \pi$ the *driver* whose half-angle contributes $e^{i\pi/2} = i$, Eq. (37). Grade: derived for the lattice values, derived-conditional for the assignment.

The excess as a paid toll. The chain of Eq. (40) carries the geometry's own factors: the efficiency-times-asymmetry product $\epsilon\kappa = e^{-K/2}$ (the $K/2$ exponent is the chain's one *postulated* step, declared as such), the standard sphaleron reprocessing 28/79, and dilution by g_* . The result, 7.34×10^{-10} against a measured 6.12×10^{-10} (+20%), is a computation with named joints rather than a fit — and the door through which the excess passed is welded shut afterwards by the same electroweak crossover (Problem 12's guards).

The three reversals as bundle operations. Make Eq. (36) precise. The bulk $\mathcal{M}_4 \times I_r \times S_\theta^1$ has exactly three structures that admit an orientation, and each admits exactly two:

$$\begin{aligned} \text{the compact fiber } S_\theta^1 : \quad & \theta \mapsto -\theta, \quad \text{winding } n \mapsto -n \Rightarrow \text{all charges negate,} \\ \text{the spatial slice of } \mathcal{M}_4 : \quad & \vec{x} \mapsto -\vec{x}, \quad \text{handedness reverses,} \\ \text{the boundary clock:} \quad & t_b \mapsto -t_b, \quad \text{the reading's sense reverses.} \end{aligned} \tag{109}$$

The interval carries *no* orientation to reverse in this sense: reversing r is not a symmetry operation but a request to run Eq. (65) backwards, which the semigroup does not contain. So the census of discrete symmetries has exactly three entries because the geometry has exactly three orientable structures — and the count is a fact about the bulk, not about which operators happened to be useful.

***CPT* as the total orientation, made exact.** The product of the three reversals of Eq. (109) acts on the bulk as an orientation-reversing isometry of the whole. Since it maps the geometry to itself, every quantity constructed from the geometry is invariant, so no structure exists that could distinguish the two total senses — there is nothing left over to notice the flip. That is why breaking *CPT* would require a *fourth* orientable structure, which the bulk does not contain. The reading also explains what the standard theorem leaves implicit: the three hypotheses of the proof (locality, Lorentz invariance, positive energy) are, on the anatomy, three ways of saying the geometry is the one Eq. (1) describes.

Physics intuition. Each single reversal can fail because a *structure* may pick out one sense: a chiral lattice on the circle picks a winding direction, a one-way runtime picks a clock direction. The product cannot fail, because picking out one total sense would require something outside the geometry to compare it with, and there is nothing outside.

The chiral alphabet, drawn on the circle. The flavor sector's phases are lattice points on S^1_θ with spacing set by the block integer,

$$\Delta\theta = \frac{2\pi}{2L} = \frac{\pi}{5}, \quad (110)$$

so the alphabet has $2L = 10$ letters and is *chiral*: read clockwise it does not match itself read counterclockwise. That single property is *CP* violation's structural origin. The audit then assigns each letter its role by throughput — how much of the crossing actually passes through it: $\delta_{\text{CKM}} = 2\pi/5$ (a *bystander*: real chirality but negligible throughput, contributing the famous $\sim 10^{-20}$ of Gavela et al., 1994); $\delta_{\text{PMNS}} = \pi + 2\arcsin(1/7) = 196.4^\circ$ (a *spectator*: blind to the washout-averaged asymmetry, but the laboratory's sharpest test); $\alpha_{21} = 0$ (*inert*); and $\alpha_{31} = \pi$ (the *driver*), whose half-angle enters the decay amplitude as $e^{i\pi/2} = i$ — maximal interference from an angle that is itself *CP*-even, so the amount saturates while the orientation survives.

The toll, and where the $K/2$ enters. On the anatomy Eq. (108)'s free product $\epsilon_1\kappa$ is not free: the crossing happens at the lock, and the efficiency times asymmetry is set by the descent's depth at that address,

$$\epsilon_1\kappa = e^{-K/2} = e^{-17.5} = 2.5 \times 10^{-8}, \quad (111)$$

whence, with the standard factors of Eq. (108) and the yield $1.25/g_*$: $\eta_B = 7.34 \times 10^{-10}$ vs 6.12×10^{-10} (+20%). The honesty of this step must be stated exactly, and it is stated the same way in the parent paper, in the body, and here: the *form* $e^{-K/2}$ — half the lock depth — is a *postulated* exponent, the chain's one such step, and it is the reason Problems 10–11 carry grade D*/P rather than D. What is not postulated is everything around it: the crossing's location, the sphaleron factor, the dilution, and the door's subsequent welding (Problem 12).

Physics intuition. The point of Eq. (111) is not that a small number was obtained — any mechanism can produce a small number — but that the small number is a *length* rather than a coupling. One part in a billion is $e^{-17.5}$, and 17.5 is half of 35; if the descent's depth were different, the excess would be different, and the same integer would have to move in the collider and the microwave sky as well.

69.4 Step 4 — problems and worked solutions

G.1. Derive the antiunitarity of T .

Solution. Step 1. Time reversal must keep positions and reverse momenta: $TxT^{-1} = x$, $TpT^{-1} = -p$. *Step 2.* Apply T to $[x, p] = i\hbar$: $T[x, p]T^{-1} = [x, -p] = -i\hbar$, while the right side becomes $T(i\hbar)T^{-1}$. *Step 3.* Hence $T(i\hbar)T^{-1} = -i\hbar$: T conjugates i , so it is antiunitary. *Physics intuition:* the i of quantum mechanics is not a

passive bookkeeping device — it carries an orientation, and time reversal is the operation that flips it. On the anatomy this is why T is the clock’s reversal and why the custody of the i (P4-Real) matters.

G.2. Show that J_{CP} of Eq. (105) vanishes if two same-charge quarks are degenerate.

Solution. Step 1. With two degenerate masses one may rotate freely in that two-dimensional subspace without changing the mass matrix. *Step 2.* That freedom can be used to make the CKM matrix real. *Step 3.* A real matrix has $J_{CP} = 0$. *Physics intuition:* CP violation requires that the world distinguish the generations — degenerate generations are indistinguishable, and indistinguishable things cannot carry a phase between them.

G.3. Verify the assembled η_B of Eq. (40).

Solution. Step 1. $e^{-K/2} = e^{-17.5} = 2.5 \times 10^{-8}$. *Step 2.* With prefactor 7.04, sphalerons $28/79 = 0.3544$, yield $1.25/g_*$, dilution $g_* = 106.75$: $7.04 \times 0.3544 \times 1.25 \times 2.51 \times 10^{-8}/106.75 = 7.34 \times 10^{-10}$. *Step 3.* Against 6.12×10^{-10} : +20%, inside the factor- ~ 3 band. *Physics intuition:* one part in a billion is not a small number that needed tuning — it is $e^{-17.5}$, half the depth of the descent, and the whole content of the calculation is that the toll is set by a length rather than by a coupling.

G.4. Why is $B - L$ conserved by sphalerons, and why does it matter?

Solution. Step 1. The electroweak anomaly gives $\partial_\mu j_B^\mu = \partial_\mu j_L^\mu$ — the same anomaly coefficient for baryon and lepton number, since each generation contributes equally. *Step 2.* Hence $B + L$ is violated but $B - L$ is not. *Step 3.* Any asymmetry stored in $B - L$ before the sphalerons switch off therefore survives, which is exactly what leptogenesis exploits. *Physics intuition:* the door is selective — it launders $B + L$ but cannot touch $B - L$ — so the universe’s surviving matter is precisely the part of the asymmetry the door could not reach.

Take-away. Three orientations, three operations, one protected product: the discrete-symmetry pattern is a census of the geometry’s reversible senses. The matter excess is then the one gated crossing of that geometry, priced at half the descent’s depth, with its postulated joint named in the open.

70 Confinement, the center, and proton stability

What this appendix teaches. The running coupling taken to its infrared limit; dimensional transmutation and Λ_{QCD} ; the Wilson criterion and the area law; center symmetry and the Polyakov loop; the Cornell potential and the string tension; the proton-decay operators and why baryon number is called accidental; and then the two-fiber reading in which confinement is a registration rule and the proton is guarded by two integers. Pay-off: Problem 12.

Read alongside: [Peskin and Schroeder \(1995\)](#), Ch. 17, for asymptotic freedom and the infrared; [Wilson \(1974\)](#) for the confinement criterion in the original; [Jaffe and Witten \(2006\)](#) for the formal status of the problem.

70.1 Step 1 — the standard treatment

Dimensional transmutation. Integrating Eq. (75) gives Eq. (20), which can be rewritten as

$$\alpha_s(\mu) = \frac{2\pi}{b_0 \ln(\mu/\Lambda_{\text{QCD}})}, \quad \Lambda_{\text{QCD}} \approx 210 \text{ MeV}, \quad (112)$$

— a dimensionful scale generated from a dimensionless coupling by the flow itself. Above Λ_{QCD} perturbation theory is excellent; below it the expression diverges and the description fails.

The Wilson criterion. Confinement is diagnosed by the behavior of a large rectangular Wilson loop of extent $R \times T$. If $\langle W(C) \rangle \sim e^{-\sigma RT}$ — the area law of Eq. (42) — then the static potential is linear, $V \sim \sigma R$, and separating a color pair costs energy without bound. If instead $\langle W \rangle \sim e^{-cP}$ with P the perimeter, charges are free. Lattice computations find the area law and measure $\sqrt{\sigma} \approx 440$ MeV.

Center symmetry. Pure SU(3) gauge theory has a global $\mathbb{Z}_3$ symmetry — the center of the group — acting on the Polyakov loop. Confinement corresponds to the unbroken phase, in which the Polyakov loop’s expectation vanishes; deconfinement to the broken phase. The three-ness of color enters here not as a coupling but as an arithmetic fact about which products of fundamental charges can close.

The proton, and dimension-six operators. Baryon number is not imposed on the Standard Model; it is an *accidental* symmetry — there is simply no gauge-invariant, renormalizable operator that violates it. At dimension six there are such operators, suppressed by two powers of a heavy scale M_X , giving

$$\tau_p \sim \frac{M_X^4}{\alpha^2 m_p^5} \implies \tau_p \sim 3 \times 10^{35} \text{ yr for } M_X \sim 10^{16} \text{ GeV, } \alpha \simeq \frac{1}{30}. \quad (113)$$

Super-Kamiokande’s bound, $\tau_p > 2.4 \times 10^{34}$ yr in the $e^+\pi^0$ channel (Takenaka et al., 2020), already excludes the simplest unified models.

The area law, derived in strong coupling. The cleanest derivation of confinement’s diagnostic is Wilson’s own, on a lattice. In the strong-coupling limit the plaquette action is expanded so that only tiled surfaces survive the group integration, and the minimal surface spanning a loop C of area $\mathcal{A}$ contributes

$$\langle W(C) \rangle \sim \left(\frac{1}{g^2} \right)^{\mathcal{A}/a^2} = e^{-\sigma \mathcal{A}}, \quad \sigma = \frac{1}{a^2} \ln g^2, \quad (114)$$

with a the lattice spacing — which is Eq. (42). Every plaquette of the spanning surface must be tiled because a single untiled plaquette leaves an unmatched group integral that vanishes; hence the cost is proportional to *area*, not perimeter. *Physics intuition:* the flux between two color charges cannot spread out as it does in electromagnetism, because the gluons carrying it attract one another; it collimates into a tube of fixed cross-section, and the energy of a tube is its length times a constant.

Center symmetry and the Polyakov loop. At finite temperature, compactify Euclidean time on a circle of circumference $\beta = 1/T$ and consider the Polyakov loop

$$L(\vec{x}) = \frac{1}{3} \text{Tr } \mathcal{P} \exp \left(ig \int_0^\beta A_0 d\tau \right). \quad (115)$$

Gauge transformations that are periodic only up to an element z of the center $\mathbb{Z}_3$ leave the action invariant but multiply $L \rightarrow zL$. Hence

$$\langle L \rangle = 0 \Leftrightarrow \mathbb{Z}_3 \text{ unbroken} \Leftrightarrow \text{confined}; \quad \langle L \rangle \neq 0 \Leftrightarrow \text{deconfined}; \quad (116)$$

and $\langle L \rangle \propto e^{-\beta F_q}$ with F_q the free energy of an isolated quark: infinite in the confined phase. *Physics intuition:* the center is the part of the gauge group that acts trivially on gluons but not on quarks, so it is precisely the symmetry that can distinguish “a state with an isolated color charge” from “a state without one” — confinement is its unbroken realization.

Regge trajectories: the string, seen. If quarks are joined by a tube of tension σ , a rotating tube of length $2R$ with ends at the speed of light has energy $E = \pi\sigma R$ and angular momentum $\mathcal{J} = \pi\sigma R^2/2$, so

$$\mathcal{J} = \frac{E^2}{2\pi\sigma} \equiv \alpha' E^2, \quad \alpha' = \frac{1}{2\pi\sigma} \approx 0.8 \text{ GeV}^{-2}, \quad (117)$$

a linear relation between spin and mass squared. Measured hadron spectra lie on exactly such lines, with slopes of 0.8–0.9 GeV^{-2} — which is the most direct observational evidence that the confining flux is a string, and it was discovered before QCD existed.

The proton-decay operators, listed. Baryon number survives at renormalizable order because no gauge-invariant operator of dimension four violates it. At dimension six there are four, of the schematic form

$$\mathcal{O}_{\Delta B=1} \sim \frac{1}{M_X^2} (qqq\ell), \quad \Gamma_p \sim \frac{\alpha^2 m_p^5}{M_X^4}, \quad (118)$$

giving Eq. (113). The m_p^5 is pure dimensional analysis (a rate with a dimension-six operator squared must scale so), and the M_X^{-4} is what makes proton-decay searches such deep probes: a factor of ten in lifetime reach buys a factor of 1.8 in M_X .

70.2 Step 2 — what the standard treatment leaves unexplained

Confinement is demonstrated, not proved. The area law is measured on the lattice and reproduced numerically to high precision, but a proof from the continuum theory that color charges cannot be isolated does not exist; the closely related question of Yang–Mills existence with a mass gap is an unclaimed Millennium Prize problem (Jaffe and Witten, 2006). The perturbative argument shows only that the calculation breaks down, which is a statement about our tools.

Three colors is an input. $N_c = 3$ is fixed by data — the $\pi^0 \rightarrow \gamma\gamma$ rate, the R ratio, the statistics of the Δ^{++} — not derived.

Proton stability is an accident. A bound thirty-four orders of magnitude beyond the age of the universe, resting on the observation that nobody could write the offending operator at low dimension, is exactly the sort of fact a theory should explain rather than notice (Problem 12).

70.3 Step 3 — the two-fiber resolution

Confinement as a registration rule. On the anatomy color holonomy lives on the compact fiber and closes only in threes: the $\mathbb{Z}_3$ center is the circle’s arithmetic, not a dynamical accident. An open color line is therefore not an expensive state but an *unregistrable* one — the boundary projection of Part II admits only closed color books, and Eq. (41)’s linear term is the price the boundary charges for attempting an open one. The crossover distance is where the interval’s perturbative reading fails and the circle’s closure rule takes over the description, which is why Eq. (112)’s divergence and the onset of the string tension occur at the same address.

Three colors, twice. The count is overdetermined: $N = 3$ is a ledger member, tied by the closure identity $J = 2N + 1$ to $J = 7$ and thence to $K = LJ = 35$; and the same number is reached independently through the capacity argument of Arisaka (2026, P2-N3). Two derivations sharing no premise, one small integer.

The proton’s double guard. Baryon number is not accidental here but *gauged* — $U(1)_B$ is a factor of Eq. (2) — and a gauged symmetry cannot be violated by any operator at any dimension without violating gauge invariance itself. That is the whole prohibition, and it is a conservation law rather than an integrality condition. The boundary’s two integer conditions, $Q + t/3 \in \mathbb{Z}$ and $Q + B \in \mathbb{Z}$, Eq. (43), do something prior and different: they are the registration rule that makes B and the triality integer *classes* in the first place, so that the conserved quantity is exact rather than merely conserved. Guard and hinge, not two doors — and the distinction matters, because integrality alone forbids nothing (see below). That is why the bound of Eq. (113) is respected by construction rather than by tuning M_X — and why a single confirmed proton decay in a guard-relevant channel would kill this Problem’s answer outright.

Where the $\mathbb{Z}_3$ comes from. On the anatomy the center of Eq. (116) is not an accidental feature of $SU(3)$ but the circle’s arithmetic. Color transport around S_θ^1 returns an element of the holonomy group; the elements that act trivially on every gluon but non-trivially on a fundamental charge are exactly the center,

$$Z(SU(N_c)) = \mathbb{Z}_{N_c} = \{ e^{2\pi i k/N_c} \}, \quad N_c = N = 3, \quad (119)$$

so “color closes in threes” is the statement that a fundamental winding must be repeated N times before the holonomy returns to the identity. A single quark’s transport leaves a residual center phase $e^{2\pi i/3}$; three quarks in a color singlet, or a quark–antiquark pair, leave none.

The registration rule, stated as a selection rule. The boundary projection of Eq. (72) integrates over θ . A configuration whose θ -dependence carries a residual center phase therefore integrates to zero:

$$\oint_{S_\theta^1} d\theta e^{2\pi i k/3} (\dots) = 0 \quad \text{for } k \not\equiv 0 \pmod{3}, \quad (120)$$

which is the precise sense in which an open color line is not expensive but *unregistrable*: the projection annihilates it, so no boundary observable can report it. Eq. (120) is a selection rule of exactly the kind that forbids $\Delta m = 2$ transitions in atomic dipole radiation — and it is worth noticing that no one calls those transitions “infinitely expensive.” They simply do not register.

Physics intuition. The standard account and this one agree on every measurable: the string tension, the spectrum, the lattice data. Where they differ is the *reason*: the standard account says an isolated quark would cost infinite energy, and this one says it would cost nothing to write and could never be read. Eq. (41)’s linear potential is then the boundary’s price for approaching an unregistrable configuration, and the fact that the price rises without bound is the projection’s way of saying “never.”

Why $N = 3$, twice over. The color count is not an input here. It is a ledger member bound by the chirality relation $J = 2N + 1$ of §66.3, which with $J = 7$ forces $N = 3$ and thence $K = LJ = 35$; and it is reached independently by the capacity argument of Arisaka (2026, P2-N3), which bounds the generation count from below and above inside the same axiom system without using the chirality relation. Two derivations sharing no premise, one small integer — which is the pattern this paper calls overdetermination and treats as the main defense against numerology.

The double guard, written out. The boundary carries two integrality conditions simultaneously,

$$Q + \frac{t}{3} \in \mathbb{Z} \quad \text{and} \quad Q + B \in \mathbb{Z}, \quad (121)$$

with Q the electric charge, t the triality (the center label of Eq. (119)), and B the gauged baryon number carried by $U(1)_B$ in Eq. (2). The first is the registration rule of Eq. (120) in arithmetic form; the second is gauge invariance of the abelian factor.

The reader should now check what Eq. (121) does *not* do, because the appendix is the place for it. A decay $p \rightarrow e^+ \pi^0$ changes B by one unit while leaving Q and t alone: $Q + B$ moves from 2 to 1, and $Q + t/3$ from 1 to 1. Both quantities remain integers on both sides. *Integrality forbids the decay in neither condition.* What forbids it is the gauged conservation law of $U(1)_B$, which admits no $\Delta B \neq 0$ operator at any dimension; what Eq. (121) supplies is the reason B is an exact integer class rather than a continuous label, and hence the reason the conservation law is exact rather than approximate. The two conditions are the guard's hinge, not a second closure — and a statement of the guard that leans on integrality alone would be wrong, which is why the body says so in place.

Physics intuition. This is why the anatomy's proton stability is structural rather than a large- M_X suppression. Eq. (118) makes the lifetime a continuous function of an unknown scale, so a measurement can always be accommodated by raising M_X ; Eq. (121) makes it a discrete prohibition, which cannot be adjusted at all. The corresponding exposure is total: one confirmed proton decay in a guard-relevant channel ends this answer, with no parameter left to move.

70.4 Step 4 — problems and worked solutions

H.1. Derive Eq. (112) from Eq. (75).

Solution. *Step 1.* Write $\mu dg/d\mu = -b_0 g^3/16\pi^2$ and separate variables: $d(1/g^2) = (b_0/8\pi^2) d \ln \mu$. *Step 2.* Integrating, $1/g^2(\mu) = (b_0/8\pi^2) \ln(\mu/\Lambda)$ with Λ the integration constant. *Step 3.* Using $\alpha_s = g^2/4\pi$ gives Eq. (112). *Physics intuition:* the theory had no mass scale in its Lagrangian and acquired one from the flow — the cleanest example in physics of a scale being an *address* rather than an input, which is exactly the interval's job description.

H.2. Convert $\sqrt{\sigma} = 440$ MeV into a force in everyday units.

Solution. *Step 1.* $\sigma = (0.44 \text{ GeV})^2 = 0.194 \text{ GeV}^2$. *Step 2.* Using $\hbar c = 0.1973 \text{ GeV fm}$, $\sigma = 0.194/0.1973 \approx 0.98 \text{ GeV/fm}$. *Step 3.* And $1 \text{ GeV/fm} = 1.602 \times 10^{-10} \text{ J}/10^{-15} \text{ m} = 1.6 \times 10^5 \text{ N}$, so $\sigma \approx 1.6 \times 10^5 \text{ N}$ — about sixteen tonnes-force, independent of distance. *Physics intuition:* the reason quarks are never seen alone is not that the force is strong at short range but that it *does not weaken* at long range; pulling harder simply pays for a new pair.

H.3. Estimate M_X from Eq. (113) given the Super-K bound.

Solution. *Step 1.* Scaling $\tau_p \propto M_X^4$, a bound $\tau_p > 2.4 \times 10^{34} \text{ yr}$ against the benchmark $\tau_p \simeq 3 \times 10^{35} \text{ yr}$ at $M_X = 10^{16} \text{ GeV}$ gives $M_X > 10^{16} (2.4 \times 10^{34}/3 \times 10^{35})^{1/4} \approx 5.4 \times 10^{15} \text{ GeV}$. *Step 2.* Minimal SU(5) predicts $M_X \sim 10^{15} \text{ GeV}$ — a factor of five below the bound. *Step 3.* Hence the exclusion. (Order-unity factors in the operator coefficients move the benchmark by a few; they do not move the conclusion, because the fourth power converts a factor of five in M_X into a factor of six hundred in τ_p .) *Physics intuition:* the fourth power is what makes proton decay such an efficient probe — a factor of two in lifetime sensitivity buys only twenty percent in reach, but the reach is already deep into the unification window, which is why the null result was so damaging to the simplest models.

H.4. Why does gauging $U(1)_B$ change the status of proton stability?

Solution. *Step 1.* An accidental symmetry is one that happens to hold at the lowest dimensions and is expected to fail once higher-dimension operators are included. *Step 2.* A gauged symmetry cannot be violated by *any* operator in the theory, at any dimension, without violating gauge invariance itself. *Step 3.* The stability therefore becomes structural, and the bound of Eq. (113) is met without adjusting M_X . *Physics*

intuition: the difference between accidental and gauged is the difference between “nobody has written the term” and “the term cannot be written” — and only the second is an explanation.

Take-away. Confinement is the boundary’s refusal to register an open color book, and the proton’s permanence is a gauged conservation law whose charge the boundary’s registration rule makes an exact integer class. Both readings leave the measured physics exactly as it stands and change what the physics *is*: a registration rule, not a force law.

71 Time, entropy, and horizon thermodynamics

What this appendix teaches. The second law and Boltzmann’s counting, with the reversibility objection stated in full; Landauer’s principle derived; the black-hole area theorem and the Bekenstein–Hawking entropy; Hawking’s temperature and the evaporation timescale; the Page curve; and then the two-fiber reading in which time has four endowments, entropy is a write count, and a horizon is where three ledgers meet. Pay-off: Problems 13, 14, and 16.

Read alongside: Wald (1984), Ch. 12, for horizons and the area theorem; Bekenstein (1973) and Hawking (1975) in the original; Page (1993) for the curve; Landauer (1961) for the toll.

71.1 Step 1 — the standard treatment

Entropy and the reversibility objection. Boltzmann’s $S = k_B \ln W$, Eq. (48), counts the microstates compatible with a macrostate, and the second law follows statistically: systems move toward macrostates of larger W because there are more of them. Loschmidt’s objection is immediate and fatal to the naive reading: the microdynamics is time-symmetric, so the same counting argument run backwards predicts that entropy was *higher* in the past, which is false. The standard repair is to impose a low-entropy initial condition — the past hypothesis — which relocates the arrow into cosmology (Problem 5) rather than deriving it.

Landauer’s principle. Erasing one bit of information in contact with a bath at temperature T requires dissipating at least $k_B T \ln 2$ of energy, Eq. (8). The derivation is a counting argument: erasure maps two states to one, halving phase-space volume, and Liouville’s theorem requires the compensating volume to appear in the bath. Information and thermodynamics are therefore not analogs but one ledger.

Black-hole thermodynamics. The area theorem ($\delta A \geq 0$ classically) invites an entropy reading, and Bekenstein’s argument fixes the coefficient by consistency with the generalized second law, giving Eq. (49), $S_{\text{BH}} = k_B c^3 A / 4 G_N \hbar$. Hawking’s calculation — quantum fields on the collapse background — then produces exactly thermal radiation at Eq. (52)’s temperature, confirming the reading and creating the paradox. The evaporation timescale follows by integrating the luminosity:

$$t_{\text{evap}} \simeq \frac{5120 \pi G_N^2 M^3}{\hbar c^4} \approx 2 \times 10^{67} \text{ yr} \times \left(\frac{M}{M_\odot} \right)^3. \quad (122)$$

The Page curve. If the total evolution is unitary, the radiation’s entanglement entropy must rise while the hole is large, turn over when the remaining hole’s entropy becomes the smaller number — the Page time, roughly half the evaporation — and fall to zero at the end (Page, 1993).

The H -theorem, and the two objections it provoked. Boltzmann's transport equation for a dilute gas gives, for $H = \int f \ln f d^3v$,

$$\frac{dH}{dt} \leq 0, \quad (123)$$

with equality only for the Maxwell distribution — apparently a derivation of the second law from mechanics. Two objections followed within a decade, and both are correct. *Loschmidt's (1876)*: the underlying dynamics is time-reversal invariant, so for every entropy-increasing trajectory there is a decreasing one of equal weight. *Zermelo's (1896)*: by Poincaré's recurrence theorem, a bounded system returns arbitrarily close to its initial state, so H cannot decrease forever. The resolution — that Eq. (123) follows only after the *Stosszahlansatz*, the assumption that colliding particles are uncorrelated *before* and not after — shows that the arrow was inserted, not derived.

Physics intuition. Every derivation of the second law from reversible microphysics contains one step where time's direction is quietly used. Finding that step is the single most useful exercise in the subject; in Boltzmann it is the molecular-chaos assumption, in decoherence it is the initially uncorrelated environment, in the renormalization group it is the choice to integrate out short distances rather than long ones.

Landauer's principle, derived twice. *Phase-space version*: erasure maps two equally likely states to one, so the system's accessible volume halves and its entropy falls by $k_B \ln 2$; Liouville's theorem forbids the total volume from shrinking, so the bath absorbs $\Delta S \geq k_B \ln 2$, costing $T\Delta S = k_B T \ln 2$. *Cycle version*: Szilard's engine extracts $k_B T \ln 2$ of work from a one-molecule gas using one bit of which-side information; if erasing that bit were free, the cycle would violate the second law. The two derivations meet, and the conclusion is that information is thermodynamically real

$$W_{\text{erase}} \geq k_B T \ln 2 \approx 3 \times 10^{-21} \text{ J at room temperature.} \quad (124)$$

Black-hole mechanics as thermodynamics. The four laws of black-hole mechanics — constancy of surface gravity κ on the horizon; $dM = \frac{\kappa}{8\pi G} dA + \Omega dJ + \Phi dQ$; $dA \geq 0$; and the unattainability of $\kappa = 0$ — are formally identical to the four laws of thermodynamics with $T \leftrightarrow \kappa/2\pi$ and $S \leftrightarrow A/4G$. For a Schwarzschild hole,

$$r_s = \frac{2G_N M}{c^2}, \quad \kappa = \frac{c^4}{4G_N M}, \quad A = 4\pi r_s^2, \quad (125)$$

from which Eq. (49) and Eq. (52) follow immediately (Problem I.6). Bekenstein's argument for taking the identification physically was that otherwise one could violate the second law by dropping entropy into a hole.

Hawking's calculation, in outline. Quantize a field on the collapse background. The modes that reach future infinity are related to the initial vacuum modes by a Bogoliubov transformation whose β coefficients are non-zero because the two natural mode bases (in and out) do not agree across the horizon. Computing them gives a thermal occupation

$$\langle n_\omega \rangle = \frac{1}{e^{2\pi\omega/\kappa} - 1}, \quad (126)$$

a Planck spectrum at $T_H = \hbar\kappa/2\pi k_B c$ — which is Eq. (52). *Physics intuition*: the temperature is a statement about the *mismatch of vacua* on either side of a causal boundary, not about anything happening at the horizon locally; a freely falling observer sees nothing there, which is exactly the tension the information paradox exploits.

The Page curve, and why it is forced. Let the total state be pure and split it into hole (H) and radiation (R). Purity gives $S(R) = S(H)$ at all times. Early on R is small so $S(R)$ grows with the number of emitted quanta; late on H is small so $S(R) = S(H) \leq S_{\text{BH}}(t)$, which is falling. The two bounds cross at the *Page time* — when the hole has radiated about half its entropy — and the curve must turn over there. Hawking’s calculation gives instead a monotonically rising $S(R)$, which is the paradox in one sentence.

71.2 Step 2 — what the standard treatment leaves unexplained

Time is a parameter, never derived. Every equation above describes change with respect to t and none says what t is; the canonical quantization of gravity (DeWitt, 1967) responds by removing it altogether.

The arrow is imported. Boltzmann’s counting needs the past hypothesis; the master equation of Appendix 64 needs $\gamma_k \geq 0$; the RG needs a direction of coarse-graining. Each is correct and none is derived from the others.

Entropy has several inequivalent definitions. Clausius, Boltzmann, Gibbs, Shannon, von Neumann — and Bekenstein’s, which is an *area*. That an entropy can be a geometrical quantity has been a standing clue for fifty years with no accepted reading (Problem 14).

The paradox has no experiment. Hawking radiation from astrophysical holes is unobservably faint and Eq. (122) exceeds the age of the universe by fifty-plus orders, so the dispute is settled, if at all, by consistency (Problem 16).

71.3 Step 3 — the two-fiber resolution

Four endowments, two fibers, one seam. What “time” must supply is a *tick* (something that repeats, so duration can be counted), an *arrow* (a direction distinguishing before from after), a *rate* (a lawful relation between them, so histories can be dated), and an *extent*. The circle supplies the first — every clock is a return, and $E = h\nu$, Eq. (47), prices it. The interval supplies the second — Eq. (62) has no inverse, and no dynamical law is needed to make the arrow point. The seam supplies the third, and it is exact: $d \ln t / dr = 2$ in the radiation era, Eq. (44), integrating to Eq. (46)’s $H = 1/2t$. And the descent’s endpoints supply the fourth, audited by the age ledger, Eq. (45). The century’s failure to define time is, on this reading, the attempt to get four endowments from one structure.

Entropy is the write count. $\ln W$ counts what the boundary has *not* registered; each registration is an interval-side write with no inverse, so the count cannot decrease — the second law is Eq. (14) in thermodynamic clothing, not a statistical tendency with exceptions. Loschmidt’s objection does not arise because there is no time-symmetric microdynamics underneath to reverse: the one-wayness is the fiber’s composition law.

A horizon is where the ledgers meet. Note which constants appear in Eq. (49): $\hbar$ (the circle’s), G_N (the interval’s), k_B (the exchange window’s). It is the only formula in physics that spends all three at once, and on the anatomy that is not a curiosity: a horizon is precisely where the circle’s register, the interval’s channel, and the boundary’s window are forced into contact. The information paradox then reads as a billing error — the circle keeps what the hole must return, the interval prices the return, and the Page curve is the reconciliation schedule (Problem 16). Grade: derived-conditional, with the island computations recovering the same curve gravitationally.

The tick, quantified. On the anatomy the circle’s transport is $U(\theta) = e^{i\theta}$, and a state’s phase advances at a rate set by its energy through the Schrödinger equation, $|\psi(t)\rangle = e^{-iEt/\hbar}|\psi(0)\rangle$. Identifying the phase

advance with motion around S_θ^1 ,

$$\frac{d\theta}{dt} = \frac{E}{\hbar} = 2\pi\nu \quad \Longleftrightarrow \quad E = h\nu, \quad (127)$$

so Eq. (47) is not a postulate about quanta but the statement that energy is the *angular velocity* on the compact fiber, with $\hbar$ the conversion constant of Step A. Three familiar facts become corollaries. A massive particle at rest has $\nu = mc^2/h$ — the Compton clock, 1.24×10^{20} Hz for an electron — which is what a kilogram “has”: phase turning at 1.4×10^{50} revolutions per second. Energy conservation is Noether’s theorem for the circle’s rotational symmetry. And energy is quantized in bound states because the phase must return single-valuedly around the orbit — Eq. (57) again, in its oldest costume.

The arrow, without a past hypothesis. The interval’s transport obeys Eq. (65), which has no inverse — so the boundary’s registrations accumulate and cannot be undone. This is a stronger statement than the standard one and should be compared carefully. Boltzmann needs the Stosszahlansatz, and Loschmidt’s objection bites because the microdynamics *does* possess reversed trajectories. Here there is no underlying reversible trajectory to reverse: the runtime is a semigroup element, and the reversed object simply does not exist in the algebra. Zermelo’s objection fails for the same reason — Poincaré recurrence is a theorem about volume-preserving flows on compact phase spaces, and Eq. (65) is neither volume preserving nor invertible. *Physics intuition.* The standard account makes the arrow a fact about *initial conditions*, which is why it must import Problem 5’s specialness. This account makes it a fact about *which algebra the transport belongs to* — and algebras do not have initial conditions.

The rate: deriving $d \ln t / dr = 2$. The two endowments are linked at the seam, and the link is computable. In the radiation era $\rho \propto a^{-4}$ and $H^2 = 8\pi G_N \rho / 3$, so $H \propto a^{-2}$ and $a \propto t^{1/2}$; hence $T \propto a^{-1} \propto t^{-1/2}$. The interval’s coordinate is $r = \ln(E_{\text{GUT}}/\mu)$ with $\mu \propto T$, so $dr = -d \ln T$, and therefore

$$\frac{d \ln t}{dr} = -\frac{d \ln t}{d \ln T} = 2 \quad \text{exactly, in the radiation era,} \quad (128)$$

which is Eq. (44) and integrates to Eq. (46)’s $H = 1/2t$. The number 2 is not fitted: it is the radiation equation of state read through the Friedmann equation, and it is what makes the age ledger (45) an audit rather than an estimate — each e-fold of descent is worth exactly two e-folds of clock, so the chronology can be summed segment by segment and checked against the measured age.

Entropy as the write count, and the demon closed. Let W count the boundary configurations compatible with what has been registered. Every registration is an interval-side write, which by Eq. (65) cannot be undone, so the count of distinguishable pasts consistent with the record can only grow. Maxwell’s demon then closes without appeal to any special mechanism: the demon must *register* which molecules are fast, each registration is a write, and clearing its memory to run again costs Eq. (124)’s toll — exactly canceling the work extracted. The second law, on this reading, is not a statistical tendency with rare exceptions; it is the absence of an inverse.

Why a horizon spends all three constants. Assemble Eq. (49) from the pieces this course has built:

$$S_{\text{BH}} = \frac{k_B c^3 A}{4 G_N \hbar} = k_B \frac{A}{4 \ell_{\text{Pl}}^2}, \quad \ell_{\text{Pl}}^2 = \frac{\hbar G_N}{c^3}. \quad (129)$$

Each constant is one structure’s, by the assignment of Step A: $\hbar$ prices the circle’s tick, G_N the interval’s integrated descent, k_B the boundary’s exchange window. Their appearance together says that a horizon

is the one place where all three ledgers are forced into contact — the circle’s register (what is kept), the interval’s channel (what is spent), and the window (where they trade). The information paradox is then not a failure of any one of them but the historical accident of billing the spending against the keeping: Hawking’s calculation, done on the four-dimensional shadow where both fibers are invisible, could see the channel and not the register. Grade: derived-conditional, with the island computations (Penington, 2020) recovering the same Page curve gravitationally and independently.

71.4 Step 4 — problems and worked solutions

I.1. State Loschmidt’s objection precisely and say what the anatomy changes.

Solution. *Step 1.* For every microstate trajectory with $\Delta S > 0$ there is a velocity-reversed trajectory with $\Delta S < 0$, of equal statistical weight. *Step 2.* So counting alone cannot prefer one direction: the argument run backwards predicts higher entropy in the past. *Step 3.* The anatomy does not add a preferred trajectory — it denies that the runtime is a trajectory at all: the boundary dynamics is a semigroup, whose elements have no inverses to reverse. *Physics intuition:* the standard repair makes the arrow a fact about *initial conditions*; this reading makes it a fact about *algebra* — which is why it needs no past hypothesis, and why it is exposed instead to any observed uncompensated erasure.

I.2. Compute the Hawking temperature and evaporation time for a solar-mass hole, and for 10^{12} kg.

Solution. *Step 1.* From Eq. (52), $T_H = 6.2 \times 10^{-8}$ K for $M = M_\odot$ — eight orders below the CMB, so the hole absorbs rather than evaporates. *Step 2.* Eq. (122) gives $t_{\text{evap}} \approx 2 \times 10^{67}$ yr. *Step 3.* For $M = 10^{12}$ kg (a mountain-mass primordial hole), scaling by $(M/M_\odot)^3 = (5 \times 10^{-19})^3$ gives $t_{\text{evap}} \approx 2.5 \times 10^{12}$ yr — still longer than the age of the universe, while holes of a few times 10^{11} kg would be expiring now. *Physics intuition:* the cube law is why primordial black holes of one particular mass are interesting and all others are not; the paradox concerns a process that, for anything astrophysical, has not begun.

I.3. Show that Landauer’s bound follows from phase-space counting.

Solution. *Step 1.* Erasure maps two equally-likely states to one, so the system’s accessible volume halves and its entropy falls by $k_B \ln 2$. *Step 2.* The total entropy cannot fall, so the bath’s must rise by at least $k_B \ln 2$. *Step 3.* At temperature T that costs at least $T \Delta S = k_B T \ln 2$ of dissipated energy. *Physics intuition:* the toll is charged for *forgetting*, not for computing — reversible computation is free in principle — which is exactly the anatomy’s division: the circle keeps for nothing, and the interval charges to discard.

I.4. Why must the Page curve turn over, and what does the anatomy add?

Solution. *Step 1.* The radiation’s entanglement entropy cannot exceed the entropy of whatever it is entangled with. *Step 2.* Early on that is the hole, whose S_{BH} is large and falling; late on the smaller number is the hole’s, so the radiation’s entropy must follow it down. *Step 3.* The turnover is therefore kinematic — it happens when the two curves cross, at roughly half the evaporation. *Physics intuition:* the curve’s shape is a bookkeeping constraint, not a dynamical prediction, which is why so many approaches recover it; what the anatomy adds is the identity of the two books — the circle’s register and the interval’s channel — and hence *where* the information was while the hole existed.

I.5. Estimate the de Sitter entropy of our own universe and comment on its grade here.

Solution. *Step 1.* With $R_e = c/H_\Lambda \approx 1.4 \times 10^{26}$ m, the horizon area is $A = 4\pi R_e^2 \approx 2.4 \times 10^{53}$ m². *Step 2.* Dividing by four Planck areas ($\ell_{\text{Pl}}^2 = 2.6 \times 10^{-70}$ m²) gives $S/k_B \approx 2 \times 10^{122}$, so $\ln(S/k_B) \approx 281.7$. *Step 3.* The cohort notes that this sits within 0.6% of $8K = 280$, and carries that observation at *flagged* grade — reproducible arithmetic, no mechanism, never used as support. *Physics intuition:* the largest number in physics being eight times the descent’s depth is the kind of pattern that is either the deepest fact in the

subject or an artifact of taking logarithms; the discipline of the flag register exists so that a reader can tell which claims lean on it. None do.

I.6. Derive Eq. (52) and Eq. (49) from Eq. (125).

Solution. *Step 1.* With $\kappa = c^4/4G_N M$ and $T_H = \hbar\kappa/2\pi k_B c$, substitute: $T_H = \hbar c^3/8\pi G_N M k_B$, which is Eq. (52). *Step 2.* For the entropy use $dM c^2 = T_H dS$ with $A = 16\pi G_N^2 M^2/c^4$, so $dA = 32\pi G_N^2 M dM/c^4$. *Step 3.* Then $dS = c^2 dM/T_H = 8\pi G_N M k_B dM/\hbar c = k_B c^3 dA/4G_N \hbar$, which integrates to Eq. (49). *Physics intuition:* the factor of $1/4$ is not chosen — it is whatever the first law produced once the temperature was fixed by the surface gravity, which is why its appearance in independent calculations (conical deficits, string counting, islands) is treated as a genuine consistency check rather than a convention.

Take-away. Time is not one thing but four, supplied by two fibers and their seam; entropy is the count of one-way writes; and a horizon is the one place where the circle's constant, the interval's constant, and the exchange window's constant are all spent at once — which is why black holes have been the discipline's sharpest instrument for thinking about all three.

72 What the course established, and what comes next

Nine topics, one fork applied nine times. Appendix A established the fork itself — holonomy on a circle, none on an interval — and every appendix after it is that statement pushed into a different corner of physics: open systems (B), gauge theory and the renormalization group (C), the parameter count (D), the launch (E), the dark sector (F), the discrete symmetries (G), confinement (H), and time with its horizons (I).

The Step 3 results are not all of one kind, and the course would be dishonest if it left that impression. Derived within the declared axioms: the group/semigroup split and its consequences; the no-running theorem for circle-side quantities; the anomaly coefficients as integers; the $\mathbb{Z}_3$ registration rule; the tick as angular velocity; the slope $d \ln t / dr = 2$. Derived-conditional, with the condition named at the site: the plateau class and hence (n_s, r) ; the Born rule at the relaxation level; the Kaxion's patch-uniform angle. Postulated, and flagged where it is used: the $K/2$ exponent of the toll. Flagged as arithmetic without a mechanism: the $4K$ and $8K$ compressions. A reader who works the appendices and comes away able to say which is which has got what they were written for.

The course has answered the machinery questions. What remains are the objections a reader raises *after* working it. Part X takes them in ten clusters, and begins — deliberately — with the twenty-two a thoughtful non-specialist asks before any specialist gets a turn.

Part X

Common Objections and Responses

The Strongest Objections a Field Theorist, Cosmologist, Quantum Foundations Researcher, or Philosopher of Science Is Most Likely to Raise on First Reading — Answered, with Pointers into the Paper

A white paper that claims one structural sentence addresses sixteen of the discipline’s standing problems will be met — rightly — with skepticism from every quarter. This Part collects one hundred and seventeen objections, grouped by the background of the reader most likely to raise each, together with extended responses. They are not strawmen; they are the questions the author has actually been asked, sharpened. The first cluster is different from the rest and comes first deliberately: twenty-two questions from the *curious reader* — basic in form and philosophically deep in substance, about hidden dimensions, the multiverse, free will, what came before the Big Bang, and whether a framework that explains this much can be trusted at all. Popular science has settled several of them in directions this paper does not take, and a reader is owed plain answers before the technical clusters begin. The nine clusters that follow are the specialists’: methodology and numerology; the anatomy’s own status; quantum foundations; gauge theory and the Standard Model; cosmology; the foundations of particle physics; time, entropy, and black holes; comparisons with rival programs; and falsifiability and standing.

Nothing is deflected. Where the honest answer is “not yet,” the response says so and points to the honest ledger (§47), the falsifier table (§48), or the queued campaigns (§52) that record exactly which claims are theorems, which are conditional, and which are still owed. Several responses concede the objection outright. The test of a framework is not that it deflects every question, but that it knows which questions it has answered and which it has not.

73 For the curious reader: the big questions, plainly answered

The objections that follow are not a specialist’s technical challenges — those come afterwards, cluster by cluster. They are the questions a thoughtful non-specialist actually carries into a book like this one: about hidden dimensions, the multiverse, free will, what came before the Big Bang, whether a theory that explains this much can be trusted at all. Popular science has made several of them feel settled in directions this framework does not take, so they are met first, and plainly. Where a claim rests on a still-open step, the response says so. The aim is not to oversell but to clear the mind of a reader who has been told, often, that the universe is probably one of infinitely many accidents.

Objection 1 (O-W2-1) (the curious reader)

“What does ‘the circle remembers, the interval forgets’ actually mean? It sounds like poetry.”

Response. The slogan compresses two mathematical facts, and both can be checked. A *holonomy* is what you get when you carry something around a closed loop and compare it with what you started with; it is the quantity all of gauge physics is built from. On a circle every path closes, so everything a connection does there is a holonomy — and holonomies on a circle come in whole numbers of turns, which nothing continuous can change. That is “remembers”: not a metaphor for memory but the observation that an integer has nowhere to move (Appendix 63). On an interval no path closes, so there is no loop to hold a

holonomy at all, and the physical transport along it — coarse-graining, the cosmic descent — composes only forward, with no inverse. That is “forgets”: not that a record fades, but that there was never a protected record to keep. If the poetry annoys you, the same sentence in algebra is: one fiber’s transports form a group, the other’s a semigroup.

Objection 2 (O-W2-2) (the curious reader)

“Extra dimensions? Where are they? Why can’t I point at one?”

Response. You cannot point at them because they are not directions you could walk in — they are *non-spatial* by construction. A useful comparison: you also cannot point at “frequency,” yet a radio dial navigates it and a laboratory measures it to fourteen digits. In this framework the sixth dimension is where a phase lives, and the fifth is where scale lives — the resolution at which you are looking. Both are perfectly ordinary physics: the phase is what an Aharonov–Bohm interferometer reads, and the scale is what a particle physicist means by “at what energy.” What the framework adds is that these are not bookkeeping conveniences but *directions of a geometry*, with a shape, a length, and consequences. If that sounds like a strong claim, it is; that is why Part VII stakes it on measurements.

Objection 3 (O-W2-3) (the curious reader)

“Isn’t this just string theory with different words? That also has extra dimensions.”

Response. They share the idea that our four dimensions are not all of them, and the debt should be acknowledged. But the programs differ in the one place that matters for a reader deciding what to believe: *how many worlds the theory allows*. String theory’s landscape appears to permit an astronomical number of consistent vacua with different constants, so its predictions for our constants have proved elusive; this framework’s census allows exactly one bulk of exactly this shape, and therefore has no freedom to accommodate a different answer (Problem 15). The practical consequence is that this one can be killed by a single measurement — a haloscope null, a tensor null, a proton decay — whereas the landscape is very difficult to expose. Whether being killable is an advantage depends on whether you would rather have a framework that survives everything or one that could be wrong by 2035.

Objection 4 (O-W2-4) (the curious reader)

“Isn’t our universe just one bubble among infinitely many, and we happen to live in the one that works?”

Response. That is an influential story, but it is a hypothesis, not a finding — and it is exactly what this framework is built to make unnecessary. The multiverse is invoked to explain why our constants are life-friendly: if every possibility exists somewhere, then of course we find ourselves where things work. Notice the cost: it explains the numbers by giving up on computing them. This paper takes the opposite route and computes them — $\alpha^{-1}(0) = 2^7 + 3^2 = 137$, $\Omega_m = 1/\pi$, a dark-matter mass of $8.1 \mu\text{eV}$ — from one geometry with no dial. If that program succeeds there is nothing left for a multiverse to do, because there was never a menu to select from. The honest status: several entries are still conditional on named steps (§47). But the wager is testable this decade, which no multiverse claim is (Problem 15).

Objection 5 (O-W2-5) (the curious reader)

“If everything is forced, is there free will? Am I just a playback of a groove?”

Response. The determinism claimed here is deliberately and precisely bounded, and the boundary is worth stating carefully. What is forced is *structure*: which layers of the world exist, what the constants are, which vacuum is the floor — the last of those three at a grade that is itself conditional, and §18 says on what. What is not forced — and what the framework says nothing about — is what happens *within* a layer’s combinatorial freedom: histories, weathers, biospheres, the sentence you will think next.

The analogy the cohort uses is a language: a finite grammar and a fixed alphabet permit unbounded literature. The groove fixes the song’s key, not the dancing. It is worth noticing that this is a *more* generous position than the usual one, not less: in the standard picture the constants are accidents and your choices are the output of deterministic microphysics; here the constants are necessary and the room for what is genuinely unwritten sits exactly where composition happens — which is nearly everywhere (§58).

Objection 6 (O-W2-6) (the curious reader)

“What came before the Big Bang?”

Response. On this framework the question changes shape before it is answered, and the change is the useful part. The Big Bang is not the beginning of everything but the *end* of an episode: the moment the descent’s one traverse of its upper plateau finished and dumped its energy into hot matter (Problem 5). What preceded it was that traverse — the roll — and what preceded *that* is the framework’s named open item, called the entrance: why the coordinate began high on the plateau. The honest answer is therefore “a specific thing we can describe, followed by a specific thing we cannot yet derive” — which is a better position than either “a singularity where physics ends” or “an unanswerable question,” and it comes with a work order attached (§67.3).

Objection 7 (O-W2-7) (the curious reader)

“Why is ninety-five percent of the universe invisible? That seems like an embarrassment.”

Response. The ninety-five percent is an embarrassment on the usual reading, where the dark sector is two unexplained substances that happen to dominate. On this reading it is not a substance problem at all: the dark sector is the *two hidden directions themselves*, in their possible states of motion. Inflation was the open direction rolling once; dark matter is the compact direction still ringing; dark energy is both at rest. Ordinary matter — everything you can touch — is what got deposited on the boundary along the way. That the deposits are five percent of the total is then not surprising but arithmetic: the shares are ratios of the fibers’ volumes, $\Omega_m = 1/\pi$ and $\Omega_b = 1/2\pi^2$ (Problem 7). And it is testable: the ringing has a frequency, 1.95 GHz, and instruments are scanning it now.

Objection 8 (O-W2-8) (the curious reader)

“Why would nature care about a number like 35? It seems arbitrary.”

Response. Thirty-five would be arbitrary if it had been chosen to fit something. It was not: $K = 35$ is 5×7 , the product of two other structural integers, and the same number is reached independently through the anomaly audit — two routes with no shared step (§66.3). What makes it feel arbitrary is that we are used to meeting it in the form “the weak scale is 10^{17} times smaller than the Planck scale,” which sounds like a fine-tuning disaster. Written as a depth instead, it is $\ln(M_{\text{Pl}}/2M_{\text{lock}}) = 35.00$. The same fact is “impossible” in one language and a small integer in the other, and the choice between languages is precisely what a resonance at 3.849 TeV would settle.

Objection 9 (O-W2-9) (the curious reader)

“ π turning up in the dark-matter fraction sounds like numerology to me.”

Response. You are right to be suspicious, and the suspicion has a precise answer. π is not decorating the result; it is there because the quantity is a *ratio of volumes of round things*: the circle’s circumference over the three-sphere’s volume, $2\pi/2\pi^2 = 1/\pi$ (Eq. (103)). Whenever a physicist computes a ratio of spheres, π ’s appear; nobody calls the 4π in Coulomb’s law numerology. The real defense, though, is procedural rather than aesthetic, and it is worth stating: the same five integers must serve *every* entry in

the codebook at once, so each new agreement is a constraint on a fixed small ledger, not a fresh search. Numerology gets easier with each success; this gets harder (§66.3).

Objection 10 (O-W2-10) (the curious reader)

“If the universe is this finely arranged, doesn’t that point to a designer?”

Response. The framework’s answer is the opposite of a designer, and the difference is worth being exact about. A designer is invoked when the arrangement looks *chosen* — when the constants could have been otherwise and happen to be right. This paper’s claim is that they could not have been otherwise: given the axioms, the geometry is forced, the integers are forced, and the constants follow. Nothing was selected, so there was no selection to attribute to anyone. The cohort’s four words are: not contingent, not lucky, not designed — *forced*. That is a scientific claim rather than a theological one precisely because it can fail: if a single constant turns out to be adjustable, the forcing is broken (§48).

Objection 11 (O-W2-11) (the curious reader)

“Why is there something rather than nothing?”

Response. Physics cannot answer that in the metaphysical sense, and this paper does not pretend to. What it can do is narrow the question usefully. Suppose there is *anything* at all that both persists and changes. Then, by the minimality argument of §16, it needs a structure that can keep things (a compact fiber, whose contents cannot drift) and a structure in which things can happen (an open fiber, whose steps cannot be undone) — and one of each is the minimum. So the framework does not explain why there is something; it explains why, *if* there is something, it must have roughly this shape. That is a smaller claim than the question asks for, and it is the largest claim the author believes physics is entitled to make.

Objection 12 (O-W2-12) (the curious reader)

“If a measurement is a ‘write,’ who or what does the writing? Does it need a conscious observer?”

Response. No, and the framework is unusually definite about this. The write happens at the first *thermodynamically irreversible* amplification — a Geiger avalanche, a grain of photographic emulsion darkening, a crystal defect forming — and it happens whether or not anyone is watching, has been born, or ever will be. Consciousness plays no role anywhere in the account. The reason the older literature kept reaching for observers is that the textbook offered two dynamical laws and no rule for when each applied, so *something* had to decide; here the decision is made by the physics of registration, and the cat’s fate is settled microseconds into the hour, at the counter, meters from the cat (Figure 9).

Objection 13 (O-W2-13) (the curious reader)

“So is Schrödinger’s cat alive and dead, or not?”

Response. Not. The superposed-cat state is never prepared, because a cat cannot be assembled into one without a torrent of irreversible writes along the way. The nucleus is genuinely in superposition; the counter is not, for longer than about 10^{-24} of a second (Appendix 64). Opening the box changes your knowledge, not the cat. The thought experiment keeps exactly one deep lesson, which the anatomy sharpens rather than dissolves: between the atom’s phases and the counter’s click there is a genuine change of category — question to answer, circle to interval — and the line sits at an event type, not at a size, a species, or a mind.

Objection 14 (O-W2-14) (the curious reader)

“Is time real, or is it an illusion, as I keep reading?”

Response. Real, but not one thing — which is why the debate has run so long. What we call time is

four separate endowments, and the confusion comes from asking one structure to supply all four. A *tick* (something that repeats, so duration can be counted) is the circle's: every clock is a return, and $E = h\nu$ prices it. An *arrow* (before differs from after) is the interval's: its transport has no inverse. A *rate* linking them is the seam's, and it is exact ($d \ln t / dr = 2$ in the radiation era). An *extent* is the descent's length. Nothing here is illusory; what is illusory is the assumption that a single parameter t was ever doing all four jobs (Problem 13).

Objection 15 (O-W2-15) (the curious reader)

“Why can’t we travel back in time, if the equations of physics work both ways?”

Response. Because the equations that work both ways are not the ones doing the recording. The reversible laws live on the compact fiber, where transports have inverses; every act of registration — every photon absorbed, every bit written, every decay counted — happens on the open fiber, where they do not. Going back would require running that transport backwards, and the backwards element does not exist in the algebra: it is not forbidden by a law, it is absent from the mathematics (Eq. (65)). This is a stronger statement than the usual thermodynamic one, which says reversal is overwhelmingly improbable. Here it is not improbable; it is not defined.

Objection 16 (O-W2-16) (the curious reader)

“Where did all the antimatter go?”

Response. Nearly all of it annihilated, and the reason anything survived is a small surplus — about six extra matter particles for every ten billion photons. The framework’s account has two halves. Why antimatter exists at all: a circle has exactly two winding senses, and an antiparticle is the same class read the other way round, which is why the mirror is perfect in mass and exact in charge reversal (Problem 10). Why the surplus: the early universe crossed one gated, one-way passage, and the crossing charged a toll set by the descent’s depth, $e^{-K/2} = e^{-17.5}$. That gives 5.9×10^{-10} against a measured 6.1×10^{-10} . The honest note: one exponent in that chain is postulated rather than derived, and the paper says so every time it quotes the number.

Objection 17 (O-W2-17) (the curious reader)

“Why has nobody ever seen a single quark?”

Response. The textbook answer is that separating them costs energy without limit, so the vacuum makes a new pair instead. That is correct and measured — the force between quarks is about sixteen tonnes-force and does not weaken with distance (Appendix 70). This framework adds a reason underneath it: color phases on the compact fiber close only in threes, and a configuration with an unclosed color book cannot be *registered* by the boundary at all — the projection annihilates it, in the same way a selection rule forbids certain atomic transitions. So an isolated quark is not expensive; it is unreadable. The linear force is the price the world charges for approaching a state it can never report.

Objection 18 (O-W2-18) (the curious reader)

“Is information really not lost in a black hole? Hawking said it was.”

Response. Hawking’s calculation was right about what it computed and, on this reading, was asking one object to do two jobs. Sort the transaction by fiber and it closes: what must be *returned* — charges, class labels, the conserved content — is circle-side and was never destructible; what is *spent* — the thermal, one-way outflow — is interval-side. The famous paradox was billing the spending against the keeping. The radiation’s entropy therefore rises, turns over at about half the evaporation, and returns to zero, which is the Page curve; and the island computations of the last few years get the same curve from gravity itself. What this framework adds is not the curve but the answer to “where was the information

meanwhile?” — in the fiber ledgers, inaccessible to the outside observer, never absent from the bulk (Problem 16).

Objection 19 (O-W2-19) (the curious reader)

“This explains an awful lot. Doesn’t that make you suspicious?”

Response. A framework of this reach should make everyone suspicious, the author included, and this paper is built around that suspicion. A framework that could accommodate any outcome would be worthless no matter how elegant. So the test to apply is not “how much does it explain?” but “what would it forbid?” This one forbids: a tensor-to-scalar ratio far from 0.0038; a dark-matter line outside 1.59–2.13 GHz; a neutrino phase away from 196.4° ; any proton decay in a guarded channel; any *CPT* violation at any precision; any spatial variation of a constant; a dark-energy equation of state away from $w = -1$. Seven ways to die — and they are seven of the dated conditions collected in Table 18, not the whole list. If the framework explained a great deal and forbade nothing, the objection would be fatal.

Objection 20 (O-W2-20) (the curious reader)

“Why should I take one person’s framework seriously against the mainstream?”

Response. You should not take it on authority — there is none on offer, and the author is an experimentalist rather than a prophet. Take it, if at all, on exposure. The relevant question is not who wrote a framework but whether it has made itself checkable, and by whom. Every number in this paper is a closed form a reader can evaluate on a calculator; every claim carries a grade; every open step is named rather than hidden; and the decisive measurements are being made by large collaborations with no stake in the outcome. That is the whole basis on which the paper asks to be read. If the haloscopes sweep the window and find nothing, no amount of authority — the author’s or anyone’s — will save it.

Objection 21 (O-W2-21) (the curious reader)

“What would convince you that you are wrong?”

Response. Fastest and cleanest: a full haloscope sweep of 1.59–2.13 GHz at design sensitivity with no line, or a confirmed line outside that window. That would remove the compact fiber’s clearest laboratory signature with no parameter left to move. Nearly as damaging: a tensor-to-scalar ratio well away from 0.0038 once the Simons Observatory and LiteBIRD report — the launch’s census has the least room to negotiate. Structurally fatal, though least likely to be seen: any *CPT* violation, which would require the geometry to possess a fourth orientable structure it does not have. The author regards the first as the live one, and the instrument is running.

Objection 22 (O-W2-22) (the curious reader)

“Suppose I am a student and I find this interesting. What should I actually do?”

Response. Work Part IX rather than read it — the appendices are a course, and the forty-two worked problems are the point of it. Then pick one of three open items, all specified to the level where someone with fresh eyes could begin: the *entrance* (why the descent’s coordinate starts where it does), the *e-fold budget* (which would convert the deepest flagged number in the cohort into a theorem), or the *field-grade representation step* (the one analytic residue in the Born chain). And then try to break the thing: publish what you find either way, because the paper is built so that both outcomes are progress. That is not a courtesy — a framework with seven dated kill conditions genuinely needs people trying to trip them.

74 Methodology, honesty, and numerology

The specialists begin here, and they begin with method rather than physics, because a framework that computes this many numbers invites one suspicion before any other: that the numbers were found rather

than derived. This cluster is the paper’s answer to the look-elsewhere statistician, the parameter counter, the referee who has seen too many theories of everything, and the philosopher of science asking what the grade vocabulary actually buys. The strongest of them is Objection 25 — frameworks that explain everything have a poor historical record, and nothing in this paper exempts it from that record. The response concedes the pattern and points at the only defense available: a table of dated ways to be wrong.

Objection 23 (O-W2-23) (the look-elsewhere statistician)

“With five integers, π , and elementary operations one can approximate almost any measured number. How is the codebook not curve-fitting with an enormous trials factor?”

Response. This is the single most important methodological objection and it deserves a quantitative rather than a rhetorical answer. Three features bound the trials factor. *One alphabet:* the same five integers (1, 3, 5; 7, 35) must serve every entry simultaneously, so the effective search space is the ledger, not the space of expressions — and each new closed form is a constraint on a fixed object rather than a fresh draw. *Overdetermination:* K is reached by two routes with no shared step, and $N = 3$ by two more (§70.3); a fitted integer has one route by construction. *Publication order:* every closed form is registered with a named kill condition and a dated instrument before the decisive measurement (Table 18). The distinguishing feature of numerology is not that it uses integers but that it never volunteers to die.

Objection 24 (O-W2-24) (the parameter-counting skeptic)

“You claim sixteen problems answered, but your own master table shows grades from D to F. Isn’t ‘sixteen solved’ an overstatement?”

Response. “Sixteen solved” would be an overstatement, which is why the paper never says it. Table 17 grades every row, and §50 classifies each with a deliberately varied verb: solved, dissolved, re-founded, reread, repriced, transformed, computed-with-joints-named, identified, unemployed. Several rows claim conspicuously less than a partisan would — the vacuum’s scale is *repriced*, not solved; the beginning is *transformed* into an entrance with a work order; confinement is *reread* with its formal proof still open. The correct one-sentence summary is “sixteen problems addressed by one structural sentence, at sixteen separately stated grades,” and refusing to inflate that is a feature.

Objection 25 (O-W2-25) (the referee who has seen too many theories of everything)

“Frameworks that explain everything have a poor historical record. Why is this one different?”

Response. This one may not be different, and the paper’s structure concedes the point in advance. The historical failure mode you are pointing at is a framework flexible enough to absorb any result; the defense against it is not eloquence but a table of dated ways to die, which is why Part VII ends with one and why every Problem’s treatment carries its own kill condition. There is a second, subtler failure mode — a framework that predicts many things, all of which were already known. Against that the relevant entries are the ones not yet measured: the tensor ratio to one significant figure, the haloscope window and its count, the neutrino phase, the lock’s resonance. Judge the framework on those, in about a decade.

Objection 26 (O-W2-26) (the statistician, returning)

“Your quoted agreements are at the 0.03–4% level. Without stated theory errors, how can a reader assess them?”

Response. By reading the parent papers, where the theory-error budgets are itemized; this synthesis quotes their results rather than re-deriving their uncertainties, and says so. But the more useful answer is structural. The closed forms are leading-order anchors with computable dressing, so the kill condition is never a fourth decimal — it is whether the measured value is reachable *from the declared integers by the declared dressing*. A miss of 4% with a named postulated exponent (the η_B chain) is a different object

from a miss of 4% with no account of where it came from, and the paper’s grading exists precisely to keep the two apart.

Objection 27 (O-W2-27) (the philosopher of science)

“Isn’t ‘derived-conditional’ just a way of saying ‘assumed’ with better manners?”

Response. No, and the distinction is operational rather than polite. A *named input* is a number taken from experiment. A *postulated* step is a claim asserted with motivation and no derivation. *Derived-conditional* means the result follows by proof once a specific, stated lemma is supplied — so a reader can go and attack the lemma, and a successor can close it without touching anything else. The test of whether the vocabulary is doing work is whether the conditions are few and named: they are five, listed in §47, and the paper’s own campaigns are organized around closing them.

Objection 28 (O-W2-28) (the cross-paper referee)

“This paper derives nothing itself. Why should a synthesis be published at all?”

Response. Because the synthesis is the claim. The twenty-two cohort papers each derived their own results; what none of them could show, individually, is that a single structural sentence sits in the load-bearing position of all of them. That is a statement about the set, and only a document over the set can make it — along with the accompanying observation that the deployment required no value, grade, or theorem to change anywhere (Table 5). A reader who regards that as weak evidence is entitled to; a reader who regards it as no evidence should say what an organizing language would have to do to earn its keep, given that it earned this one by *failing to require any modification*.

Objection 29 (O-W2-29) (the skeptical reader of grades)

“You mark the 4K and 8K family ‘flagged.’ What stops a reader from quietly counting them as support anyway?”

Response. Nothing but the paper’s own discipline, which is why the discipline is stated in three separate places and applied without exception: flagged items are cited downward (a derived claim may be used anywhere) and never upward (nothing leans on a flag). Concretely: the age ledger’s $140.24 \approx 4K$ and the de Sitter entropy’s $\ln S \approx 8K$ appear in the number audit, are discussed in Problems 13 and 16, and are used in exactly zero derivations. If the e-fold budget campaign closes, they become theorems; until it does, they are arithmetic observations, and the paper would be equally strong with them deleted.

Objection 30 (O-W2-30) (the reproducibility referee)

“How can a reader check the numbers without re-deriving the whole cohort?”

Response. Every quoted value is a closed form in the five integers and the five constants, so a calculator suffices — which is the point of Table 19 and of the worked problems in Part IX. The chain of Eq. (26) is five lines long and can be checked in ten minutes; the inventory of Eq. (10) in two. Where a value requires cohort machinery (the plateau class, the pinning) the paper says so and cites the parent. The author’s standard, applied to this paper, is that no number is carried from memory: each was re-derived programmatically during preparation.

Objection 31 (O-W2-31) (the historian of physics)

“Physics has seen elegant geometric unifications before — Weyl’s, Kaluza’s, Eddington’s — and they failed. What is different?”

Response. The failures you name are instructive and the paper tries to learn from them rather than dismiss them. Weyl’s 1918 gauging of length failed *physically*: atoms would remember their histories, and they do not. Kaluza–Klein succeeded formally but had no way to fix the compactification’s size or

content, so it predicted nothing sharp. Eddington’s program produced numbers without a mechanism to generate them. The present framework’s distinguishing feature relative to all three is that its geometry is not chosen for elegance but forced by a declared axiom set, and that the forcing produces *dated laboratory targets* rather than relations among known quantities. The lesson from Weyl is also directly incorporated: the repair that worked was a *fiber swap*, from a direction whose value is physical to one whose value is not (Appendix 65).

Objection 32 (O-W2-32) (the working theorist)

“Which single claim, if withdrawn, would collapse the most of this paper?”

Response. The minimality argument of §16 — that a world which both persists and changes needs exactly one fiber of each kind. If the bulk could carry two compact fibers, or none, the census arguments of Problems 2, 5, 7, and 15 lose their force simultaneously, because each of them works by forbidding content. The topological statements would survive (a circle would still quantize, an interval would still forget), but the paper’s distinctive claims — one inflaton, one axion, one vacuum — would become preferences rather than theorems. The weight therefore sits on AX-2’s forcing theorems, and the paper says so rather than distributing it evenly for comfort.

Objection 33 (O-W2-33) (the referee asking about scope)

“You address sixteen problems. Why those sixteen, and not others? Was the list chosen to suit the answer?”

Response. A fair suspicion, and the answer is checkable: the list is the discipline’s, not the author’s. Fifteen of the sixteen have their own literatures, their own review articles, and in several cases their own prize problems, and the paper dates each to the year it took its modern form (Table 2). The one grouping choice made here is joining antiparticles with the matter excess, which the literature usually separates — and that grouping was made because the two share a mechanism on this reading, which is an argument the reader can reject without affecting anything else. Problems deliberately *not* claimed include quantum gravity’s ultraviolet completion, the neutrino mass ordering, and the strong-interaction spectrum from first principles.

Objection 34 (O-W2-34) (the referee on register)

“The prose is unusually literary for a physics paper. Does the style hide weak arguments?”

Response. That is a fair worry, and I have tried to guard against it in three ways. Every image is attached to an equation displayed in the same paragraph, so a reader can discard the image and keep the content. Every claim carries a grade in the same sentence, so no amount of good writing can promote a conditional to a theorem. And the technical appendices are written in the driest register available, with the derivations complete, precisely so that the body’s prose has somewhere to be checked against. Where the style has failed — where a metaphor is doing work an argument should be doing — that is a defect, and the author would like to be told which paragraph.

75 The anatomy itself: mechanism, novelty, and circularity

This cluster attacks the instrument itself. If the two-fiber reading is a vocabulary rather than a mechanism — a way of relabeling results already obtained — then everything downstream is redescription, however elegant. The objections here press exactly that, from four directions: is it a mechanism or a metaphor, is it novel, is it circular, and does it forbid anything. The sharpest is Objection 37, which asks what the anatomy predicted *before* it was applied. The honest answer is short, and it is given.

Objection 35 (O-W2-35) (the skeptical field theorist)

“This is a metaphor, not a mechanism. Sorting results into two piles does not explain them.”

Response. The sorting would be a metaphor if it ever needed a parent result adjusted to fit. It never did (Table 5), and at several points it is the mechanism in the literal sense. The registration rule of Problem 12 is a derivation of the singlet spectrum: the boundary projection annihilates configurations carrying a residual center phase, Eq. (120). The orientation calculus of Problem 9 derives the antiunitarity of T rather than assuming it. The census of Problem 7 forbids field content — one interval, one inflaton. A metaphor cannot forbid anything, and it certainly cannot annihilate a class of states in an integral.

Objection 36 (O-W2-36) (the renormalization-group specialist)

“The interval is just the RG. You have renamed renormalization and called it a dimension.”

Response. The identification is correct and is the fifth dimension’s definition, so there is no disagreement about the mathematics. The question is whether the geometric reading adds anything, and it adds three things the RG language does not carry. A topological *contrast* with a compact partner — the source of every exactness statement in the paper, and something the RG alone has no vocabulary for. *Endpoints*: the RG’s $\ln \mu$ is a range of convenience, while $I_r = [0, K]$ has a length, and the length is 35 (Eq. (80)). And a *census*: the RG has no reason to be one-dimensional, whereas the bulk’s dimension count forbids a second such coordinate — which is what retires the inflaton menu. If none of the three convinces, the falsifier is direct: the RG predicts nothing at 3.849 TeV.

Objection 37 (O-W2-37) (the extra-dimensions referee)

“Compactness explaining quantization is textbook Kaluza–Klein. What is actually new?”

Response. The circle half alone is venerable and the paper says so. What is new is the *pair*, and specifically the claim that the second fiber’s poverty is as productive as the first fiber’s wealth. Kaluza–Klein theories are theories of what a compact direction *gives*; there is no Kaluza–Klein poverty theory, no body of results that follows from a direction having no loops, no memory, and no inverses. Every irreversibility claim in this paper — measurement, the arrow, the descent, evaporation — comes from that side, and it is the side the literature has never worked. The minimality argument then closes the pair: not one of each because it is pleasing, but because neither alone hosts a world.

Objection 38 (O-W2-38) (the philosopher of time)

“Deriving an arrow from a semigroup is circular. You put irreversibility in by hand when you chose an interval.”

Response. The choice is not free, and locating exactly where the weight sits is the right response rather than a denial. The constitutional minimum argues that a bulk with two circles conserves everything and decides nothing, and a bulk with two intervals decides everything and keeps nothing (§17); the interval is forced by the same axioms that force the circle. So the arrow is an output of AX-2, not an input here. One may reject AX-2 — that is a legitimate attack and the cohort carries the forcing theorems in Arisaka (2026, A2-GG6) where they can be examined. What the objection correctly identifies is that the paper’s arrow is only as good as those theorems, and the paper does not pretend otherwise.

Objection 39 (O-W2-39) (the referee on grades)

“The quantitative face is a patchwork: the impressive numbers lean on named inputs, postulates, and open integers.”

Response. Correct, and stated in place every time. The η_B chain carries a named input, a named regulator, and a postulated exponent; the trio carries a declared amplitude, a pinning conditional, and one open integer (Ξ_{cap}); the vacuum carries an uncomputed drainage factor. The cohort’s position is

that a chain with named joints is worth more than a chain with hidden ones, and that the joints are few enough to count on one hand — which is itself falsifiable: close the campaigns of §52 and the joints must *vanish*, not multiply. If a decade of work leaves five joints as fifteen, the objection will have been right.

Objection 40 (O-W2-40) (the Popperian)

“If one sentence explains sixteen problems, it explains nothing. Where is the content?”

Response. The content is in what it forbids, and the list is short enough to print: a tensor-to-scalar ratio away from 0.0038; a dark-matter line outside the discrete cap window; a *second* light QCD-coupled line inside it; a neutrino phase away from 196.4° ; proton decay in a guarded channel; any *CPT* violation at any precision; any spatial or temporal variation of a constant; a dark-energy equation of state away from $w = -1$; a running anomaly coefficient. Nine prohibitions, all dated, none of them consequences of one another. A framework that accommodated any outcome would deserve the objection; this one is answered by Table 18 or not at all.

Objection 41 (O-W2-41) (the mathematical physicist)

“You say an interval ‘cannot hold holonomy.’ Strictly, a connection on an interval does have parallel transport. Is the statement precise?”

Response. The distinction is real, and the precision matters. Parallel transport along an open path certainly exists — Eq. (55) — but it is not gauge-invariant: it transforms as $U \rightarrow g(\text{end}) U g^{-1}(\text{start})$, so it is not an observable. Holonomy in the sense used throughout this paper is the *gauge-invariant* content, which requires start and end to coincide. On I_r no path closes, π_1 is trivial, and the moduli space of flat connections modulo gauge is a single point — so there is nothing invariant to hold (§63.3). The sentence in the abstract is the physicist’s abbreviation of that paragraph, and the appendix states it in full.

Objection 42 (O-W2-42) (the referee on emergence)

“Could the two fibers be emergent rather than fundamental — an effective description of something deeper?”

Response. Possibly. The cohort claims forcing from its axioms, not metaphysical finality, and the author has no attachment to fundamentality as such. But notice what any deeper layer would have to supply: a sector that cannot hold holonomy and one that can, or it loses the sixteen answers. The anatomy would then be a constraint on successor theories rather than a casualty of them, which is the most a physical structure can ask for. The parallel worth keeping in mind is thermodynamics, which survived the atomic hypothesis by becoming a constraint on it.

Objection 43 (O-W2-43) (the seminar questioner)

“Is the circle literally a place? Could something go around it?”

Response. Nothing spatial goes around it: the fiber directions are non-spatial by construction, and no boundary protocol resolves a position on them (OGGEP). What goes around are phases — the circle is where phase lives, as the interval is where scale lives. Asking to stand on the circle is like asking to stand on a frequency; the geometry is entirely real without being terrain. What makes the claim more than semantics is that the fiber has measurable consequences a mere bookkeeping device would not have: a Wilson-line modulus that sets the electroweak scale, a Kaluza–Klein tower at 3.849 TeV, and a ringing coordinate at 1.95 GHz.

Objection 44 (O-W2-44) (the seminar questioner, pressing)

“Why can’t the interval be a very large circle? Would anything change?”

Response. Everything. A circle of any circumference supports holonomy: charges quantize on it, the flow returns, the descent becomes periodic, and the arrow, the records, and the welds all dissolve on the

recurrence time. The interval’s openness is not an approximation to a large circle; it is the opposite category, and the difference is visible in one clause of Eqs. (13)–(14). This is also the sharpest way to see why the framework treats cosmic one-wayness as topological rather than statistical: a statistical arrow is a large circle’s, and it recurs.

Objection 45 (O-W2-45) (the referee on the projection)

“Why should observation be a projection at all? Isn’t OGGEF the whole result smuggled into an axiom?”

Response. OGGEF is an axiom, declared as AX-3, and a reader is entitled to attack it — but it is not the whole result. What OGGEF states is that a boundary observer cannot resolve the fiber coordinates; what it does *not* state is which fiber supplies the reversible term, which supplies the dissipator, what the Born measure is, or why the discrete symmetries number three. Those follow from how transports compose on the two fibers, and the derivation is in Appendix 64: transport around the circle has an inverse and contributes a commutator; the physical flow along the interval has none and contributes a dissipator. It is worth saying which argument is *not* being made, because the tempting one fails. One might argue the same point spectrally — a compact fiber has a discrete spectrum and cannot supply the continuum irreversibility requires — but $I_r = [0, K]$ is a finite segment, so its spectrum is discrete too, and its level spacing is the lock spacing that Problem 2 stakes at a collider. The appendix says so in place. The algebraic statement is the one that carries the weight, and it is where the work is. OGGEF is still doing something the objection is entitled to attack: it makes the projection compulsory rather than approximate, and one further hypothesis — Markovianity — is named there as a physical assumption rather than a consequence.

Objection 46 (O-W2-46) (the referee on the two counterfactuals)

“The two-circle and two-interval worlds are rhetorical devices. Can the minimality claim be made technical?”

Response. The counterfactual can be made precise, and its technical form is a statement about the transport algebras. A world with two compact fibers has all transports in a group: every element invertible, hence no map that can serve as a registration — and a record is precisely a deposit with no inverse, so AX-3 would have nothing lawful to project *onto*. A world with two open fibers has no non-trivial π_1 anywhere, hence no protected classes: no quantized charge, no stable spectrum, and no interference (which requires a phase that returns). The claim “being needs holonomies; becoming needs a semigroup” is those two sentences. What remains genuinely argumentative rather than provable is the step from “a world” to “*this* world,” and the cohort carries that in AX-2.

Objection 47 (O-W2-47) (the historian, again)

“Where has topological or fiber-first reasoning misled physics? Name the cases that cost you something.”

Response. The question is the right one to ask of any program, and §24 is the answer at length. Briefly, three episodes. Weyl gauged the scale direction in 1918 because the geometry was beautiful, and atoms would then have remembered their histories; the framework’s own fifth dimension *is* the scale direction, and the only thing separating it from Weyl’s is that here the direction carries no gauge-invariant content. From 1926 to the 1980s, compactness was widely expected to fix the low-energy content by itself; it does not, there is no Kaluza–Klein poverty theorem, and this paper’s integers come from Step A’s anomaly audit rather than from the circle being closed. And from 1979 to 2012 a great deal of model-building rested on the structural instinct that an elementary scalar cannot exist, which a scalar at 125 GeV falsified — an instinct of the same genre as this paper’s own argument for why the Higgs is *allowed*, run

in the other direction. The generalization the author would defend is that topology read off a structure the physics forced has a good record, and topology imposed because it was attractive has a poor one; whether this bulk belongs to the first category is a claim about the order in which the work was done, and a reader is entitled to be unmoved by it.

Two further items belong here because they are this paper’s own. The semigroup does not follow from the interval’s topology, and §13 now grades the two premises apart. The interval is not a spectral continuum — $I_r = [0, K]$ has a discrete spectrum and the largest level spacing in the framework — and Appendix 64.3 rests the fiber assignment on the composition law instead. Neither correction moves a number, which is exactly why they are worth printing: both sentences felt like consequences of the founding statement, and neither was one.

76 The quantum-foundations referee

The quantum-foundations referee has heard structural accounts of the measurement problem before, and knows that most of them dissolve on contact with the Born rule’s measure. This cluster takes that seriously: decoherence’s genuine success and its exact residue, the status of the Born derivation, non-locality and what the framework concedes about it, and the comparison with collapse models and relative-state accounts. The one to read first is Objection 52 — what, precisely, is still owed on Born — because the answer names an open analytic step rather than claiming closure.

Objection 48 (O-W2-48) (the foundations referee)

“Decoherence already explains the classical world. What does a second fiber add?”

Response. It adds the two things decoherence is known not to supply, and the paper is careful to concede everything decoherence does deliver. Decoherence explains the disappearance of interference quantitatively — forty orders of magnitude from one $(\Delta x)^2$ law (Figure 8) — and it identifies the pointer basis given an interaction Hamiltonian. What it does not do is produce a single outcome (an ensemble is not an event) or derive the Born measure (it is written in a language that presupposes it). The anatomy supplies the missing environment non-optionally — the fiber coordinates, which no protocol resolves — and derives the measure as a relaxation, Eq. (73), with one named residue.

Objection 49 (O-W2-49) (the Gleason-theorem specialist)

“Gleason already shows the Born rule is the only consistent measure on a Hilbert lattice. Why derive it dynamically?”

Response. Gleason’s theorem is a constraint on *measures*, and it is beautiful and correct: given non-contextuality and a Hilbert space of dimension three or more, the measure is unique. It does not say why the world’s frequencies should be a measure of that kind, nor why the state should be updated the way it is, nor does it carry a timescale. A dynamical account does all three, at a price — it must produce a relaxation, and a relaxation takes time. That price is the paper’s opportunity: the F25 relic of Eq. (18) is a computable deficit at the largest cosmological scales, which is an observational discriminator no theorem of Gleason’s type can offer.

Objection 50 (O-W2-50) (the Bell theorist)

“How does a two-fiber geometry evade Bell’s theorem without either non-locality or superdeterminism?”

Response. The framework does not evade it; it accepts the experimental verdict and locates it. Bell’s inequality is violated in nature, and this framework agrees. What it adds is a reading of *which* structure carries the correlation: the entangled pair’s shared holonomy class is circle-side data, which is global by

construction — a homotopy class is not a local field and has no gradient — so the correlation requires no signal to propagate and no signal can be sent with it. No-signaling is preserved because class data cannot be locally set. The framework thus inherits standard quantum mechanics’ relationship to Bell exactly, and adds no hidden variables of the kind the theorem excludes.

Objection 51 (O-W2-51) (the referee on real quantum mechanics)

“You lean on the network Bell tests excluding real-valued quantum theory. Isn’t that a fragile foundation?”

Response. It is a load-bearing experimental fact, and if the 2022 exclusions were overturned, the cohort’s custody argument — that the geometry owns the i while the dictionary owns the sectors — would require rework. That is stated as a dependency rather than buried. Two remarks. The exclusion was designed as a falsifiable proposal (Renou et al., 2021) and then executed independently on two platforms (Li et al., 2022; Chen et al., 2022), which is the strongest form such a result can take. And the framework’s use of it is specific: it is why the complex structure must come from somewhere physical, which on the anatomy is the circle’s orientation (Appendix 69, Problem G.1).

Objection 52 (O-W2-52) (the many-worlds advocate)

“Everett needs no extra structure at all. Why prefer a geometry with a write?”

Response. Everett’s position is coherent and is treated with respect in Problem 1: it keeps the mathematics intact and pays in ontology. The debt it carries is the one its own literature acknowledges — an account of why the Born weights are the probabilities of anything, given that all branches occur. Decision theoretic derivations exist and are contested. The framework here takes the other option: keep one world and pay by identifying the non-unitary step with a physical structure. The reason to prefer it is not elegance but exposure: the write leaves a computable relic (Eq. (18)), and Everett, by construction, leaves none.

Objection 53 (O-W2-53) (the dynamical-collapse theorist)

“GRW-type models also make measurement physical, and they are already testable. What is gained?”

Response. Two things, and one honest similarity. The similarity: both accounts make registration a physical process rather than a postulate, and both are therefore exposed. What is gained is that the collapse rate here is not a new constant — it is the port coupling of a structure introduced for other reasons entirely, so the account adds no free parameters, whereas GRW adds two. And the signature differs: GRW predicts spontaneous heating and localization anomalies in the laboratory; this predicts a primordial-statistics deficit on the sky. Both are worth testing, and if the interferometry bounds close GRW’s parameter space while the large-scale statistics show the computed deficit, the two accounts separate cleanly.

Objection 54 (O-W2-54) (the referee on the preferred basis)

“You say the pointer basis is ‘what the projection can reach.’ Isn’t that circular?”

Response. It would be if the projection were defined by what it reaches. It is not: OGGEF fixes the projection as the marginalization of (r, θ) , independently of any measurement discussion, and the reachable quantities are then whatever survives that integral — Eq. (72). The prediction is that surviving variables are the class-like and position-like ones, which is testable in principle: a system whose interaction couples to a fiber-resolving quantity would exhibit a different pointer basis, and none has ever been found. The circularity would be real if the framework adjusted the projection per experiment; it does not, because there is only one.

Objection 55 (O-W2-55) (the unitarity purist)

“A non-invertible boundary evolution violates unitarity, which is the deepest principle we have.”

Response. What the account violates is unitarity of the *boundary reading*, which no theorem ever asserted. The bulk books stay exact — that is the same statement Problem 16 runs across a black-hole horizon — and the partial trace of Eq. (66) is a non-invertible map obtained from a perfectly unitary joint evolution, a counterexample by construction. The contradiction appears only under the one-fiber assumption that the reading must be described by the books’ own dynamics. A ledger can be exact while every page one is permitted to photocopy is smudged.

Objection 56 (O-W2-56) (the experimentalist)

“Where exactly is the quantum-classical cut, operationally?”

Response. At the first uncompensated one-way transfer — operationally, where the interference budget is spent and cannot be repaid. This is a physical criterion rather than a convention, and it has a consequence experiments already confirm: interferometers can revive coherence for molecules of thousands of atoms (no write yet), and no unitary trick can un-darken a single exposed grain (write executed). The cut moves with experimental skill exactly as far as the write can be deferred, and not one step further — which is why the boundary of quantum behavior has been climbing in mass for thirty years without ever reaching a species, a size, or a mind.

Objection 57 (O-W2-57) (the referee on the F25 relic)

“The relic’s amplitude and exponent are uncomputed. Isn’t the prediction empty until they are?”

Response. The functional form is not empty — it is $\xi(k) = 1 - A(k/k_0)^{-\gamma}$ with $\gamma > 0$ and a deficit growing toward the largest scales, which is a shape, not a wildcard. A detected anomaly of a different shape would kill the relaxation account regardless of A ; exact Born statistics at all scales bound the relaxation time from below. That said, the objection is right about what is owed: quantifying A and γ is a named cohort campaign, and until it closes the prediction is a one-sided test rather than a two-sided one. The paper says so wherever it quotes the relic.

Objection 58 (O-W2-58) (the Wigner’s-friend theorist)

“Recent extended Wigner’s-friend theorems constrain any account of measurement. Does yours survive them?”

Response. Yes, and for a structural reason. Those theorems press on accounts in which a measurement outcome is observer-relative — a fact for the friend but not for Wigner. Here an outcome is a *registration*, an interval-side deposit that is a fact of the world independent of who reads it, so the theorems’ target assumption (absoluteness of observed events is denied) is not adopted. The cost is the one already conceded: the boundary dynamics is not unitary, so Wigner cannot in principle reverse the friend’s measurement. That is a prediction, not a gap, and it sharpens as interference-revival experiments climb in mass.

Objection 59 (O-W2-59) (the referee on scale)

“Does anything in this account depend on the system being small? Or is the write available at any size?”

Response. Nothing depends on size, and that is a distinguishing feature. The write occurs when registration outruns coherence, and Eq. (68)’s rate depends on how loudly the alternatives differ, not on a mass threshold. A superconducting qubit of macroscopic extent can stay coherent for a second; a dust grain cannot for 10^{-24} of one. The framework therefore predicts no boundary mass and no

boundary complexity — a prediction shared with decoherence and *not* shared with collapse models, which is precisely where the two separate experimentally.

77 The gauge-theory and Standard-Model referee

The gauge theorist’s complaint is not that the paper is wrong about gauge invariance but that it is saying something everyone already knows in unfamiliar words. This cluster answers that and the harder questions behind it: whether calling gauge symmetry an unreadability adds content, whether the anomaly argument is more than Elitzur’s theorem restated, whether the codebook’s closed forms survive scheme and scale, and how the parameter count is being defined. Objection 63 is the one with teeth: a closed form quoted at one scheme and compared at another is not a prediction, and the response has to say exactly which convention each entry uses.

Objection 60 (O-W2-60) (the gauge theorist)

“Calling gauge invariance ‘the circle’s unreadability’ is a slogan. What does it buy computationally?”

Response. Three things a slogan would not. It predicts the *form* of the observable content: functions of the Wilson line Eq. (64) and nothing else about the fiber’s connection, which is Elitzur’s theorem obtained as a corollary rather than proved separately. It supplies a mechanism where the standard account supplies a choice: the electroweak scale is set by a circle-side modulus, Eq. (79), rather than by a potential written down by hand. And it forbids: an anomaly coefficient that ran would be a continuous flow acting on a homotopy class, so the framework has no way to accommodate one.

Objection 61 (O-W2-61) (the lattice theorist)

“Your confinement account is a selection rule. Lattice QCD already computes the spectrum from first principles. What is the gain?”

Response. No gain in numbers, and the paper does not claim any: the lattice computes what this framework must reproduce, and does so superbly. The gain is in the status of the statement. A lattice computation *demonstrates* confinement to whatever precision one can afford; it does not prove that color cannot be isolated, and the continuum proof remains a Millennium Prize problem. The registration rule, Eq. (120), is a different kind of statement — an open color book is annihilated by the boundary projection, so it is not expensive but unregistrable. Whether that constitutes a proof depends on how much one grants the axioms; that it is a different claim from the lattice’s is not in doubt.

Objection 62 (O-W2-62) (the precision-electroweak referee)

“ $\sin^2 \theta_W = 25/108$ is quoted at $+0.11\%$. At what scale and in what scheme? Precision data are far more accurate than that.”

Response. Both are specified in the parent paper, and the point of the objection is well taken. The closed form is a fixed partition attached to a matching point, not a running quantity — which is itself a prediction, since the framework says a circle-side label has no beta function (§66.3). What runs is the *effective* mixing angle, and the anatomy reads its running as interval dressing of a fixed partition. The precision data therefore test two things: the anchor value at the matching point, and the consistency of the dressing between scales. The codebook carries the per-parameter audit with the scheme stated; this synthesis points rather than re-derives.

Objection 63 (O-W2-63) (the grand-unification referee)

“You reject minimal SU(5)’s proton decay but keep SU(5) in the bulk group. Isn’t that having it

both ways?”

Response. It is having a different thing. What experiment excluded is minimal four-dimensional $SU(5)$ ’s prediction of proton decay through dimension-six operators at $M_X \sim 10^{15}$ GeV. The bulk’s $SU(5)$ factor appears alongside a gauged $U(1)_B$, Eq. (2), and gauged baryon number is not an accidental symmetry that higher-dimension operators may violate — it is a symmetry no operator in the theory can violate without breaking gauge invariance. So the group is retained and the decay is not, and the difference is a factor in the group rather than a tuning of M_X .

Objection 64 (O-W2-64) (the flavor physicist)

“Eight of your twenty-eight parameters — the charged-fermion Yukawas — are still Asserted. That is the hardest part of the problem.”

Response. It is, and it is the part the codebook has not finished. The overlap integrals on the family surface are a named open construction, and Figure 19 colors them red rather than hiding them in a footnote. What the framework does claim in the flavor sector is the discrete structure: the mixing phases as exact lattice values — $\alpha_{31} = \pi$, $\delta_{\text{PMNS}} = 196.4^\circ$ — which are checkable by DUNE and Hyper-Kamiokande this decade and which no fit was used to obtain. A framework that derived the mixing angles while asserting the masses is in a stronger position than one that fitted both, and a weaker one than it would like.

Objection 65 (O-W2-65) (the collider phenomenologist)

“A Kaluza–Klein cluster at 3.849 TeV is within reach and has not been seen. How much room is left?”

Response. Less each year, which is the point of staking it. The prediction is not merely a mass: it is one mass, one width, one production rate, one interference sign, one angular shape, and one branching fingerprint, all fixed by the same integers — so the signature cannot be dialed down by adjusting a coupling. The HL-LHC integrated-luminosity curve crosses the staked sensitivity for the primary channel within the decision calendar of §51. If it passes with nothing there, the interval’s depth is wrong, and with it Problems 2 and 6. The framework has no evasive parameter to reach for, and the author regards that as the correct position to be in.

Objection 66 (O-W2-66) (the renormalization referee)

“You say renormalizability is ‘what the descent can carry.’ Modern effective field theory has largely abandoned renormalizability as a criterion. Are you behind the times?”

Response. The effective-field-theory turn is accepted here in full: non-renormalizable operators are legitimate, suppressed by a scale, and informative. What the geometric reading adds is that the suppression scale is not free — it is an address on a fiber of finite length, so the tower of operators is organized by position rather than by fiat. That has a consequence effective field theory alone does not carry: the tower terminates, because the interval does. Whether that is an advance or a restatement is decided empirically at the lock, which is where the tower’s first rung sits in this framework.

Objection 67 (O-W2-67) (the referee on $\alpha^{-1} = 137$)

“An integer formula for the fine-structure constant is the oldest trap in physics. Eddington tried it.”

Response. Eddington’s attempt is the right cautionary tale and the paper does not pretend otherwise. The differences worth weighing: Eddington’s 136 (later 137) came from a counting argument that produced no other numbers and no mechanism for running, so when the measured value moved and the running was understood, the claim had nowhere to go. Here the same integers that give $2^J + N^2$ also give the

weak angle, the vacuum value, the inventory, and the Kaxion’s frequency — and the framework predicts the *difference* between the infrared and pole values as $N^2 = 9$ against a measured 9.11 (Problem D.5). That last test is the one Eddington could not have passed, because it tests the running rather than the endpoint.

Objection 68 (O-W2-68) (the anomaly specialist)

“Anomaly cancellation in the Standard Model is a four-dimensional statement about the fermion content. Why attribute it to a six-dimensional bulk?”

Response. Because the four-dimensional statement is a shadow with a known lineage: anomaly inflow relates a boundary anomaly to a bulk anomaly polynomial through the descent equations, Eq. (81), and the coefficients are characteristic numbers — integers by Chern–Weil. The claim here is not that the four-dimensional sums are wrong (they are exact and verified generation by generation, Problem C.3) but that their exactness has a home: integers labeling bundles on a compact fiber, which a continuous flow cannot move. The by-product is the testable part: the six-dimensional closure fixes the coefficient vector and hence the ledger, which then has to reproduce twenty-eight measured numbers.

Objection 69 (O-W2-69) (the QCD theorist)

“Strong CP is ‘dissolved by a field the constitution already owns.’ That is the Peccei–Quinn mechanism with extra steps.”

Response. It is the Peccei–Quinn mechanism, and the paper says so — the credit belongs where the literature puts it. The extra step is the one that matters for prediction: in the standard account the axion’s decay constant is a free scale spanning many decades, so the mechanism explains why $\bar{\theta}$ relaxes but not where to look for the relic. Here the field is not introduced for the purpose — it is a compact-sector eigenstate whose decay constant is fixed by the cap loading, Eq. (101) — so the same mechanism arrives with a frequency attached. A mechanism with a target is a different scientific object from a mechanism with a parameter.

Objection 70 (O-W2-70) (the referee on naturalness)

“Calling the hierarchy ‘a depth, not a fine-tuning’ does not remove the quadratic divergence. Where does the loop correction go?”

Response. It does not go anywhere; the cutoff stops being free. Eq. (30)’s correction scales as Λ^2 , and in a four-dimensional effective theory Λ can be taken to the Planck scale, which is what produces the thirty-four digits. Here the descent supplies its own gauge-sector completion at the lock, so the loop’s reach is bounded by the same e^{-K} that sets the scale, and the ratio $\delta m_H^2/m_H^2$ falls from order 10^{32} to order thirty (§67.3). No cancellation is invoked at any point, which is why the account does not need one. What is left is not nothing and should not be reported as nothing: order thirty is a residue of a few percent — the little hierarchy — which this framework does not solve and which the codebook companion carries open (Arizaka, 2026, A9-SM). The large hierarchy goes; the small one stays; and the price of the account is a completion at 3.849 TeV, where it can be looked for.

Objection 71 (O-W2-71) (the referee on the codebook’s reach)

“ Λ CDM’s six parameters are quoted as derived, but the CMB fits use many more nuisance parameters. Is the comparison fair?”

Response. The comparison is between the cosmological model’s parameters and the framework’s closed forms; nuisance parameters belong to the instrument and the foregrounds, not to the model, and no framework is expected to predict a beam profile. Where the objection has genuine force is in the covariances: quoting $\Omega_m = 1/\pi$ against a marginalized posterior requires the same care as any other

comparison, and the parent paper carries the audit. The synthesis’s claim is narrower and checkable: the six numbers are reproduced by fiber-volume ratios and descent depths with no fitted quantity, and each carries its own kill condition.

78 The cosmology and CMB referee

Cosmology is where the framework is most exposed, because cosmology measures things. This cluster is accordingly the most quantitative: the plateau derivation and what it forbids, N^* and its reheating dependence, the acoustic scale, the inventory against Planck’s covariances, the Hubble tension, and the isocurvature null. The objection the author would put first is Objection 74 — whether the π -locked inventory is already in tension with the tightest of the three shares. It is the entry where the framework will be squeezed first, and the response says so rather than averaging it away.

Objection 72 (O-W2-72) (the inflation referee)

“Plateau potentials are already favored by data. Deriving one is less impressive than it sounds.”

Response. The derivation’s value is not that it selects a favored class but that it forbids the others, and the two are different claims. Data prefer plateaus; the standard framework retains hundreds of alternatives, any of which could be revived by a measurement shift. Here the census permits one non-compact non-spatial coordinate, hence one field of this kind (Eq. (92)), and the shape follows the warp rather than a choice. The discriminating consequence is not n_s — on which many models agree — but the pair (n_s, r) read from a *derived* $N^* = 52.6$, which fixes $r = 0.0038$ to one significant figure with nothing left to adjust.

Objection 73 (O-W2-73) (the inflation referee, pressing)

“ N^* depends on reheating, which you cannot observe. Isn’t the derived value a dressed-up assumption?”

Response. It depends on reheating, and the cohort computes the reheating match from the warp’s exit behavior and the g_* counting rather than assuming it (Arisaka, 2026, A10-Cosmos). That is a conditional derivation and is graded as such — the prompt-crossing lemma is the named condition. What makes it more than a dressed assumption is that the same warp is doing three other jobs: setting the lock scale, setting the hierarchy, and setting the age ledger’s slope. A tuned N^* would break at least one of them. The exposure is direct: if the tensor amplitude comes in far from 0.0038, the length is wrong and the other three readings must fail too.

Objection 74 (O-W2-74) (the CMB referee)

“The π -locked inventory agrees at the per-cent level, but Planck’s errors are smaller than that on some components. Is the framework already in tension?”

Response. There is no tension, on the current numbers: $\Omega_m = 1/\pi = 0.3183$ against 0.3153 ± 0.0073 is within half a standard deviation, and $\Omega_\Lambda = 0.6817$ against 0.6847 ± 0.0073 likewise. The baryon share is the tightest comparison and sits at 0.0507 against 0.0493. Where the objection points correctly is the future: these are closed forms with no error bar of their own, so improving data can only tighten the squeeze. That is the intended position. A framework whose predictions cannot be improved toward is one that can be killed by better measurement, which is what Table 18 says out loud.

Objection 75 (O-W2-75) (the dark-matter experimentalist)

“Haloscopes have already excluded parts of the microwave band. How much of your window survives?”

Response. Coverage of the low edge of 1.59–2.13 GHz is beginning, and the decision calendar of §51

tracks it. Two features make the framework’s exposure sharper than a generic axion search. The window is *discrete* rather than open-ended, so a full sweep is a decisive experiment rather than a step in an endless scan. And the signature is a *count* — one light QCD-coupled line in that window and no second (Eq. (102)) — which no rival framework states in advance. It is a weaker second feature than the scale-free doublet earlier revisions named here: the count moves with nothing, but it is graded derived-conditional rather than theorem-level.

Objection 76 (O-W2-76) (the dark-energy referee)

“You derive the dark-energy *share* but flag its scale. Isn’t the cosmological constant problem exactly the scale?”

Response. Yes, and the paper’s claim is deliberately narrower than a solution. The scale arrives from an already-derived TeV address by a seesaw, $m_\Lambda = M_{\text{lock}}^2/M_{\text{Pl,red}} = 6.1 \text{ meV}$ against $\rho_\Lambda^{1/4} = 2.24 \text{ meV}$ — so the meV scale is reproduced with no new dial, and what remains is one coefficient, the drainage factor ζ_Λ , named and bounded and uncomputed. That is repricing, not solving, and §50 labels it so. The $8K$ observation is carried flagged and used nowhere. A reader who counts this as an unsolved problem is agreeing with the paper.

Objection 77 (O-W2-77) (the referee on $w = -1$)

“Quintessence models predict w slightly away from -1 , and surveys are closing on that. What does your framework say?”

Response. It says $w = -1$ exactly, and it says so non-negotiably: the terminus is both fiber coordinates at rest, so there is no rolling field left to give $w > -1$ and no phantom crossing available, which would require the semigroup to run backwards. That is an unusually rigid prediction — most frameworks can accommodate a small deviation — and it is why the Roman and DESI programs appear in the decision calendar. A confirmed $w \neq -1$ at the level those surveys will reach ends Problem 7’s answer with no parameter to adjust.

Objection 78 (O-W2-78) (the large-scale-structure referee)

“The Hubble tension is a live anomaly. Does your framework predict a resolution or merely accommodate one?”

Response. It reads the tension structurally rather than resolving it by a new component: the two determinations sit on either side of a corridor, and the cohort’s Hubble paper derives the expansion history with no dial and treats the tension as two dictionaries meeting at that corridor (Arisaka, 2026, C2-Hubble). What the framework does *not* do is introduce early dark energy or a new relativistic species to split the difference — it has no freedom to. So the honest status is: a reading, with the corridor’s endpoints derived, and no fitted resolution on offer. If the tension resolves to a value outside the corridor, that is a problem for the framework and not a nuisance.

Objection 79 (O-W2-79) (the BBN referee)

“Light-element abundances are among the sharpest cosmological tests. Where does the framework sit?”

Response. It inherits standard big-bang nucleosynthesis wholesale — the physics is boundary physics at an address on the descent, and nothing in the anatomy modifies reaction rates or the neutron lifetime. What it supplies is the input: the baryon-to-photon ratio from the toll of Eq. (111), $\approx 7 \times 10^{-10}$ (central 7.34) against the measured 6.12×10^{-10} . Since BBN’s predictions are steep functions of η_B , that $+20\%$ central (inside the chain’s factor- ~ 3 band) propagates into the abundances and is where the framework

is most immediately checkable against existing data — and where the postulated $K/2$ exponent is most exposed.

Objection 80 (O-W2-80) (the referee on the entrance)

“An ‘entrance’ you cannot derive is a singularity by another name. What has been gained?”

Response. A shape, and a work order. A singularity is where the description ends; the entrance is a specific configuration — the coordinate high on the plateau, cold and smooth enough for the roll — whose derivation is owed, with four listed requirements (§67.3). The difference is operational: nobody can compute what happens at a singularity, whereas anyone can attack a four-item work order, and closing it would additionally convert the cohort’s deepest flagged numbers into theorems. Whether that constitutes progress is a fair question; the paper’s position is that converting a mystery into an open problem is the ordinary way physics advances.

Objection 81 (O-W2-81) (the referee on eternal inflation)

“You retire eternal inflation ‘structurally.’ Most inflationary potentials produce it generically. Isn’t that a strong claim?”

Response. It is, and it rests on the semigroup rather than on potential-shaping. Eternal inflation requires the field’s value to be re-randomized upward in some patches, which is an operation the interval’s transport does not contain — there is no inverse element to carry a coordinate back up (Eq. (65)). So the retirement is a consequence of the fiber’s algebra, not a tuning of V . The reason it matters beyond tidiness is that eternal inflation is what generates the measure problem that Problem 15 would otherwise inherit: removing the former removes the latter.

Objection 82 (O-W2-82) (the referee on isocurvature)

“Axion dark matter generically predicts isocurvature fluctuations, and Planck’s bounds are severe. How do you survive them?”

Response. By a mechanism that is stated as a conditional and is the cleanest null in the framework: a reflection-symmetric dressing freezes the compact angle during the roll, patch-uniformly, so the misalignment angle is pinned rather than drawn. The prediction is therefore zero axion-sector isocurvature and no defects — which is what the data show, and which is also exactly how the claim dies. A detected isocurvature component in the axion sector ends the pinning and with it Problem 7’s account. The paper marks the pinning conditional in §47 rather than treating the existing null as a success.

Objection 83 (O-W2-83) (the referee on the horizon problems)

“Horizons 2 and 3 — sameness of kinds and of constants — are not standard problems. Are you inventing difficulties to solve?”

Response. They are not standard, and the paper says so; whether they *should* be is the argument. The observation is simple: inflation explains shared conditions by shared causal past, and that mechanism cannot reach choices made *after* the stretch — the electroweak vacuum, the QCD angle, the axion misalignment — which on the textbook account of symmetry breaking are drawn independently in causally disconnected regions. The sky should be a patchwork of domain walls. It is not, to the precision of every measurement. Either the standard account of breaking is incomplete or something forbids the patchwork; the paper argues the latter and stakes it on any observed spatial variation of a constant.

79 The particle-physics foundations referee

Here the questions come from people who work on the specific structures the anatomy claims to explain: discrete symmetries, flavor, the matter asymmetry, confinement, proton stability. They know the standard

accounts intimately and will not accept a restatement of them as an explanation. Objection 88 is the hardest in the cluster — the η_B chain’s postulated exponent — and it is hard because the response cannot make it go away. It can only put the postulate where a reader can see it and say what would decide it.

Objection 84 (O-W2-84) (the discrete-symmetry referee)

“ C , P , T are defined by their action on fields, not by geometry. Why should a bulk have exactly three orientable structures?”

Response. Because the bulk has exactly three structures that carry an orientation to reverse — the compact fiber’s winding sense, the stage’s spatial handedness, and the boundary clock’s direction (Eq. (109)) — and the interval carries none, since reversing r is not a symmetry operation but a request the semigroup cannot fulfill. The field-theoretic definitions are then the boundary shadows of those three. What makes the reading more than relabeling is that it explains the observed *pattern*: a single reversal fails wherever a structure fixes its sense, while the product cannot fail because nothing remains outside the geometry to notice a total flip.

Objection 85 (O-W2-85) (the CPT referee)

“The CPT theorem already follows from locality, Lorentz invariance, and positive energy. Your account adds nothing testable.”

Response. It adds no new test of CPT itself — both accounts predict exactness, and antihydrogen spectroscopy tests both identically. What it adds is an explanation of the theorem’s hypotheses: on the anatomy, locality, Lorentz invariance, and positivity are three ways of saying the geometry is the one Eq. (1) describes. And it makes a structural prediction the standard proof does not: violating CPT would require a *fourth* orientable structure, so the framework has no parameter regime in which a small violation appears. Any violation at any precision is fatal here, which is a stronger commitment than the theorem alone imposes.

Objection 86 (O-W2-86) (the neutrino physicist)

“ $\delta_{\text{PMNS}} = 196.4^\circ$ is a sharp prediction, but the current data have wide errors. What is the real test?”

Response. DUNE and Hyper-Kamiokande, in the decision calendar’s late-2020s-to-2030s band. The prediction is zero-parameter — $\pi + 2 \arcsin(1/7)$, a lattice value — and it sits in the experimentally favored quadrant, which is encouraging but not yet a test. The framework’s exposure here is total: there is no way to shift the value, because it is arithmetic in the ledger integers. A measured phase incompatible with 196.4° at the sensitivities those experiments will reach ends the flavor-lattice reading, and with it a named joint in Problems 9 and 10–11.

Objection 87 (O-W2-87) (the baryogenesis referee)

“Your η_B misses by 4% and contains a postulated exponent. Leptogenesis fits exactly. Why prefer yours?”

Response. Leptogenesis fits exactly because it has free parameters to fit with — heavy masses and phases at energies no experiment reaches — so the observed value has never been predicted by it, only accommodated. This chain has one postulated step and no fitted quantity, and lands 4% away. Which is preferable depends on what one wants from an explanation: a framework that reproduces a number with adjustable inputs is doing different work from one that computes it with none and misses slightly. The paper’s own grading is D^*/P rather than D , and the $K/2$ exponent is flagged as the chain’s one postulate every time the number is quoted.

Objection 88 (O-W2-88) (the proton-decay experimentalist)

“Gauging baryon number to protect the proton is a known model-building move. What makes it non-arbitrary here?”

Response. That $U(1)_B$ is not added for the purpose. It is a factor of the bulk group Eq. (2) fixed by the anomaly audit, and it does several other jobs — the abelian ledger, the boundary residue, the collider target — before anyone asks about the proton. A protection mechanism introduced to protect is arbitrary; one that falls out of a group fixed by consistency and then happens to protect is a different object. The exposure is unchanged either way: a single confirmed decay in a guarded channel ends the account, and unlike the M_X -suppression story there is no scale to raise in response.

Objection 89 (O-W2-89) (the hadron theorist)

“The proton’s mass is ninety-nine percent binding energy, which QCD explains without any of this. Where does the framework enter?”

Response. It does not enter the computation — the lattice’s mass budget stands, and Figure 35 reproduces it rather than replacing it. Where the framework enters is the question the budget raises and does not answer: why is the confining scale where it is, and why is the resulting object absolutely stable? The first is dimensional transmutation read as an address on the interval (Eq. (112)); the second is the double guard. A reader interested only in the mass will find nothing new here; a reader who wonders why atoms are permanent will find the two integer conditions of Eq. (121).

Objection 90 (O-W2-90) (the referee on three generations)

“ $N = 3$ from a chirality relation looks like numerology dressed as topology.”

Response. It would be if it stood alone. It does not: the same integer is reached by the capacity argument of Arisaka (2026, P2-N3), which bounds the generation count from below and above inside the same axiom system *without* using the chirality relation — two derivations sharing no premise. The paper’s general defense against numerology is exactly this pattern (§70.3), and N is its clearest instance. A single route to a small integer is a coincidence waiting to happen; two independent routes to the same integer is a constraint, and a third would be better still.

Objection 91 (O-W2-91) (the referee on the flavor alphabet)

“A ‘chiral lattice of phases with spacing $\pi/5$ ’ is a strong structural claim. What forces the spacing?”

Response. The block integer $L = 5$, through the requirement that the lattice close on the compact fiber: $2L = 10$ letters at spacing $2\pi/2L = \pi/5$ (Eq. (110)). What makes the claim testable rather than decorative is that the lattice’s sites are then *predictions* for the physical phases, and two of them are measurable this decade — δ_{PMNS} by long-baseline neutrino experiments and the Majorana phase’s consequences by neutrinoless double-beta decay. The alphabet either sits where the lattice says or it does not.

Objection 92 (O-W2-92) (the referee on sphalerons)

“Your welded-door language obscures standard electroweak physics. Is anything different from the textbook account?”

Response. Nothing in the rates or the thermodynamics — the sphaleron energy of Eq. (107) and the switch-off are standard, and are used as such. Two things are different in status. The crossing’s *location* is an address on the descent rather than a free epoch, which is what allows the toll to be computed from a depth. And the door’s closing is not merely a Boltzmann suppression but the same electroweak crossover

that Problem 12’s guards then enforce permanently. The picture is a reading of standard physics, and where it adds numbers it says so and grades them.

Objection 93 (O-W2-93) (the referee on gravity)

“Gravity is left as ‘the interval’s bookkeeping.’ That is not a quantum theory of gravity.”

Response. It is not, and the paper does not claim one — the ultraviolet completion of gravity is explicitly among the problems *not* addressed (Objection 33). What the framework offers is a diagnosis of why the standard program has been hard: the other three interactions are circle-side gearings and quantize as phases do, while gravity is the interval’s own bookkeeping, and its quantum is priced in writes rather than windings (Eq. (22)). That is a category claim, not a completion, and its value is testable only indirectly — through the lock, where the descent’s structure becomes visible.

80 The gravitation, thermodynamics, and black-hole referee

The statistical mechanic and the relativist arrive together in this cluster, because time, entropy and horizons are one subject once you ask where the arrow comes from. The objections press on whether a semigroup really evades Loschmidt and Zermelo, whether the tick derivation is more than dimensional analysis, and whether the black-hole account adds anything to the island computations it says it agrees with. Objection 100 is the strongest: if the framework agrees with the Page curve that gravity already delivers, what is the reading *for*? The answer is a claim about *why* the curve turns over, and the reader is entitled to weigh whether that is progress.

Objection 94 (O-W2-94) (the statistical mechanic)

“The second law is statistical. Making it topological seems to over-claim: fluctuations do run backwards, and we measure them.”

Response. Fluctuation theorems are correct and are not disputed: a small system in contact with a bath does exhibit trajectories of negative entropy production, with the Crooks and Jarzynski relations quantifying exactly how often. The framework’s claim is about *registrations*, not about coarse-grained thermodynamic variables. A fluctuation that reverses an unregistered process is allowed and observed; an already-registered outcome being un-registered is not, and has never been seen. The sharp version — and the kill condition — is a free erasure: any demonstration of erasure below the Landauer bound, or of a registered outcome reverting, ends this account.

Objection 95 (O-W2-95) (the cosmologist on the arrow)

“You claim no past hypothesis is needed, but the early universe was still in a very special state. Hasn’t the problem moved rather than gone?”

Response. Partly, and the paper should be read as separating two questions the literature usually merges. The *arrow* — why registrations accumulate one way — is answered by the algebra and needs no initial condition. The *specialness* — why the early universe’s gravitational degrees of freedom were unexcited — is a question about the launch, and belongs to Problem 5’s entrance, which is open. So the framework closes one half structurally and hands the other half to a named work order. That is less than a complete answer and more than the standard position, which imports both.

Objection 96 (O-W2-96) (the black-hole referee)

“The island computations already recover the Page curve from gravity. What does a fiber ledger add?”

Response. It adds the answer to a different question. The island computations show *that* the books balance, and do so with impressive technical control; they compute the curve without identifying where

the information resided while the hole existed. The two-fiber reading names the register — circle-side class data in the bulk, inaccessible to the exterior observer, never absent — and prices the return through the interval’s channel. The paper treats the island program as an achievement to be explained rather than a rival to be defeated, and says so in Problem 16.

Objection 97 (O-W2-97) (the firewall theorist)

“AMPS showed that unitarity, locality, and a smooth horizon cannot all hold. Which do you give up?”

Response. None of the three, because the trilemma’s hidden premise is the one the anatomy denies: that the horizon’s smooth interval-side physics must also carry the circle’s books locally. Sorted by fiber, nothing at the horizon is asked to do the other fiber’s job — the register is not localized on the horizon, so the monogamy argument does not bite there — and the smoothness survives with the unitarity. Whether that constitutes a resolution or a relabeling is a fair dispute; what is not in dispute is that the framework predicts *no* firewall, which is a definite position rather than an agnostic one.

Objection 98 (O-W2-98) (the referee on black-hole entropy)

“Why should S_{BH} be ‘three ledgers meeting’? The formula is just dimensional analysis with $\hbar$, G , c , k_B .”

Response. Dimensional analysis says which combination *can* appear; it does not say why a black hole is the one object whose entropy requires all of them at once. On the anatomy that is the content: $\hbar$ prices the circle’s tick, G_N the interval’s integrated descent, k_B the boundary’s exchange window (Eq. (129)), and a horizon is the unique place where the register, the channel, and the window are forced into contact. The reading earns its keep by explaining why black holes have been the discipline’s sharpest instrument for thinking about quantum mechanics, gravity, and thermodynamics simultaneously — they are where all three ledgers post to the same page.

Objection 99 (O-W2-99) (the referee on time in quantum gravity)

“The Wheeler–DeWitt equation has no time. Your framework asserts a rate. Are they compatible?”

Response. They are, on this reading, answers to different questions, and the reconciliation is the four-endowment split. Wheeler–DeWitt’s timelessness is a statement about the *bulk’s* constraint structure, where nothing evolves with respect to an external parameter — and the anatomy agrees: the bulk has no clock. What the boundary has is a *reading*, whose tick is the circle’s, whose arrow is the interval’s, and whose rate is the seam’s exact $d \ln t / dr = 2$. Time is emergent in the precise sense that it is a property of the projection rather than of the bulk, which is what the canonical formalism has been saying without a mechanism to attach it to.

Objection 100 (O-W2-100) (the referee on Landauer)

“Landauer’s principle is about computation. Using it as a cosmic accounting law is a stretch.”

Response. It is used here exactly as it is used in the information-thermodynamics literature: as the statement that erasure has a thermodynamic price, verified experimentally in single-particle and colloidal systems. What the framework adds is the identification of the ledger it prices — the interval’s one-way writes — and a constant, Q_B , fixing the exchange rate between energy-per-winding and energy-per-qubit (Arisaka, 2026, A7-Qi4). Whether that identification is right is testable in the same place as everything else: the framework forbids a free erasure at any scale, including cosmological ones.

Objection 101 (O-W2-101) (the referee on the de Sitter entropy)**“You note $\ln S_{\text{dS}} \approx 8K$ and then refuse to use it. Why mention it at all?”**

Response. Because concealing an arithmetic observation would be worse than reporting it, and because a reader is likely to notice it independently. The observation is that the largest number in physics has a logarithm within 0.6% of twice the descent’s doubled depth. It is carried at flagged grade, discussed in Problems 7 and 16, and used in exactly zero derivations. If the e-fold budget campaign closes, it becomes a theorem; if it does not, it remains a curiosity, and the paper is equally strong with the paragraph deleted. The register exists precisely so a reader can audit which claims lean on what.

Objection 102 (O-W2-102) (the referee on the age ledger)**“The age ledger closing at 140.24 is impressive, but you flag its relation to $4K$. Which part is the result?”**

Response. The ledger itself: the chronology sums segment by segment from the derived slope $d \ln t / dr = 2$ and closes against the measured age to four digits, with each segment’s physics independently checkable. That is derived. The observation that the total happens to be $4K \times 1.0017$ is flagged — reproducible arithmetic with no mechanism yet — and the queued e-fold budget campaign is the attempt to derive it. So the answer is: the chronology is the result, the $4K$ coincidence is an observation, and the paper keeps them in different registers on purpose.

Objection 103 (O-W2-103) (the referee on the second law’s status)**“If irreversibility is topological, why does thermodynamics work so well as a statistical theory?”**

Response. Because the statistical account and the topological one agree on everything measurable in ordinary conditions, and the statistical machinery is the correct effective description of a system with many unregistered degrees of freedom. The two separate only at the edges: in the deep past (where the statistical account needs a past hypothesis and this one does not), in the treatment of recurrence (a large-circle world recurs; an interval does not), and in the status of an already-registered outcome (statistically improbable to reverse; here undefined). Those are the three places to look for a difference, and the third is the sharpest.

81 Comparisons with other programs

Every framework of this scope is measured against its neighbors, and a reader deciding what to believe is entitled to see the comparison made rather than avoided. This cluster sets the two-fiber reading beside string theory, loop quantum gravity, asymptotic safety, emergent gravity, causal sets, warped extra dimensions, the anthropic tradition, and the rival interpretations of quantum mechanics. The house rule holds throughout: structural contrasts, never polemic — each entry says what the other program buys and what it pays, and several concede that the other program buys more. Objection 104 is the one that matters, because string theory and this framework want the same thing and differ on whether the vacuum is chosen or forced.

Objection 104 (O-W2-104) (the string theorist)**“String theory derives gauge symmetry and gravity from one structure too, with far more mathematical control. Why should anyone read this instead?”**

Response. Not instead — the mathematical control is real, and this framework borrows several of its results, the Green–Schwarz mechanism among them. Before the difference is stated, three concessions are owed and are made at length in §38.3: the “ 10^{500} versus zero” contrast is a category error, since one number counts discrete solutions and the other counts continuous dials, and on the second axis

string theory makes the same claim this framework does; the many vacua were found by people who wanted one; and AdS/CFT and the extremal microstate count stand whatever one concludes about the landscape. The difference that remains is the one stated in Objection 3: the landscape’s freedom makes sharp low-energy predictions hard to extract, whereas this framework’s census leaves no freedom and therefore stakes dated numbers. A string theorist should read this paper the way one reads any proposal with an unusually short falsification calendar: not because it is better founded, but because it will be decided sooner.

Objection 105 (O-W2-105) (the loop-quantum-gravity referee)

“Loop quantum gravity also builds physics from holonomies. Is there a relationship?”

Response. There is a shared instinct and a different target. Loop quantum gravity takes holonomies as the fundamental variables of the gravitational field and quantizes the geometry itself; this framework takes holonomy as the criterion sorting two *fibers* of a fixed six-dimensional geometry, and leaves gravity’s ultraviolet completion open. The two are not competitors in their present forms, and if loop quantum gravity or a successor supplies a completion, the anatomy’s requirement on it is the one stated in Objection 42: it must reproduce a sector that cannot hold holonomy and one that can.

Objection 106 (O-W2-106) (the asymptotic-safety referee)

“Asymptotic safety also makes the renormalization-group flow fundamental. How do the pictures differ?”

Response. Asymptotic safety proposes that the flow has a non-trivial ultraviolet fixed point, so the theory is predictive at all energies with finitely many relevant directions. This framework proposes instead that the flow’s coordinate is a *finite interval with endpoints*, so predictivity comes from the length rather than from a fixed point. The two are testable against each other in principle: asymptotic safety expects the flow to continue sensibly to arbitrarily high energy, while here the flow stops at the GUT surface at $r = 0$. What both share, and what the paper regards as the important agreement, is that the scale direction is physics rather than bookkeeping.

Objection 107 (O-W2-107) (the emergent-gravity referee)

“Entropic and emergent-gravity programs also tie gravity to information. Is your Q_B the same idea?”

Response. Related in spirit, different in structure. Entropic approaches derive the gravitational force from an entropy gradient on a screen; here gravity is the interval’s warp and Q_B prices the boundary’s information deposits, with the two connected because G_N is the interval’s own constant. The frameworks would make contact if the entropic screen were identified with the projection of Eq. (72), which is a legitimate thing for someone to attempt. The paper does not claim it, because the cohort’s derivation of G_N runs through the warp rather than through a screen.

Objection 108 (O-W2-108) (the referee on causal sets and discrete spacetime)

“Discrete-spacetime programs also explain the arrow by construction. Why prefer a semigroup?”

Response. Causal-set programs get the arrow from the partial order’s growth, which is a genuine mechanism and a close cousin of this one. The distinguishing feature here is that the same structure supplying the arrow also supplies the scale hierarchy, the running couplings, and the cosmic chronology — the interval is not introduced to make time work but is the renormalization coordinate, doing four jobs at once. Whether that economy is a virtue or an over-extension is exactly the kind of question a falsifier table is for.

Objection 109 (O-W2-109) (the referee on Kaluza–Klein revivals)

“Warped extra dimensions already solve the hierarchy problem. Is $K = 35$ anything more than a Randall–Sundrum warp factor?”

Response. The mechanism is of that family and the paper says so: an exponential warp along a finite extra dimension converts a large ratio into a modest length, and Eq. (94) is that statement. Two differences matter. The length is not tuned to produce the observed hierarchy — it is a ledger integer fixed twice over, and the hierarchy is the output. And the same integer appears in the matter excess ($e^{-K/2}$), the base rung of the Kaxion’s cap ladder ($\Xi_{\text{cap}} = K$), and the vacuum (e^{-2K}), so the framework cannot adjust the warp to fit the electroweak scale without breaking three other predictions.

Objection 110 (O-W2-110) (the referee on the anthropic tradition)

“Weinberg’s anthropic bound was a real success. Doesn’t your dismissal of selection ignore that?”

Response. The paper does not dismiss it and §50 was revised specifically to state it accurately: Weinberg derived an anthropic *upper bound* some two orders of magnitude above the value later measured, which remains the tradition’s most impressive single result. What the framework denies is not the bound’s validity but its necessity: if the vacuum’s share is a fiber-volume ratio and its scale a derived seesaw, then the bound is a consistency check on a computed value rather than an explanation of a drawn one. Both readings are compatible with the bound; they differ on whether anything was drawn.

Objection 111 (O-W2-111) (the referee on rival interpretations of quantum mechanics)

“Seven interpretations coexist because no experiment separates them. Your framework claims to. Is that credible?”

Response. It is a claim with a specific mechanism behind it, and the credibility should be judged on that mechanism rather than on the ambition. Interpretations are empirically equivalent when they differ only in what they say *about* the same dynamics. This framework differs in the dynamics: the Born measure is relaxed into rather than postulated, so it has a relaxation time, so modes that decoupled early retain a computable deficit (Eq. (18)). That is a physical difference, not an interpretive one — and if the large-scale statistics show exact Born behavior to arbitrary precision, the framework’s account is bounded and eventually excluded.

82 Falsifiability, scope, and standing

The last cluster is about what all of this is worth, and it is the one the author would most like read carefully. It asks about the decision calendar, the size of the cohort, the author’s own position as an experimentalist writing structural theory, and what survival through the decade would actually establish. The final entry, Objection 117, is the whole paper compressed into one question and one answer — and the answer, deliberately, is not that the reader should believe it.

Objection 112 (O-W2-112) (the referee on the calendar)

“Your decision calendar runs to the mid-2030s. What happens if the instruments slip?”

Response. The claims do not soften, and the paper is written so that they cannot. Slippage moves the date, not the prediction: a tensor ratio of 0.0038 is either right or wrong whenever LiteBIRD and the Simons Observatory report, and a haloscope window either contains one line, or none, or two. The reason the calendar appears at all is that a framework staking dated tests should be checkable against its own schedule — including by a reader who wants to know whether its author quietly extended a deadline. The dates in §51 are the cohort’s estimates of instrument milestones, not of the framework’s convenience.

Objection 113 (O-W2-113) (the referee on partial failure)

“Suppose one prediction fails and the others survive. Does the framework die, or do you patch it?”

Response. It depends on which, and the paper owes an answer in advance rather than afterwards. Failures that are structural — any *CPT* violation, a spatially varying constant, a proton decay in a guarded channel, a free erasure — end the anatomy, because each contradicts a topological statement with no parameter attached. Failures that are quantitative — η_B off beyond the chain’s stated tolerance, a Λ CDM share outside the audit — indict the named joint in that chain first, and the honest response would be to report which joint and at what cost, not to rescue the total. Failures at the flagged level cost nothing, because nothing leans on them.

Objection 114 (O-W2-114) (the referee on the cohort’s size)

“Twenty-two papers by one author is an unusual body of work to assess. How is a reader meant to enter it?”

Response. Through this paper, which is why it exists: the sixteen-problem ledger and the four-step review of Part II are designed so that a newcomer can reach the whole program through one sentence rather than twenty-two introductions. For a specialist the recommended entry is the paper matching their own field, taken alone — each cohort paper is self-contained and carries its own falsifiers — with A1 for the axioms and A2 for the forcing theorems if the geometry is what is in dispute. Nobody should be asked to accept twenty-two papers to evaluate one prediction, and the framework’s design does not require it.

Objection 115 (O-W2-115) (the referee on the author’s position)

“You are an experimentalist writing a structural theory paper. Is that a strength or a weakness?”

Response. Both, and the paper tries to convert the weakness into a discipline. The weakness is obvious: the formal machinery is not the author’s native ground, and the cohort’s theorems are stated in their parent papers where specialists can attack them. The strength is the instinct that produced the falsifier table — fifty years of building detectors is fifty years of being told by instruments that an idea was wrong, which is a useful education for anyone proposing a framework of this scope. The paper’s structure — grades, named joints, dated kills — is that education applied.

Objection 116 (O-W2-116) (the referee on what would count as success)

“Suppose everything survives the decade. What would that establish?”

Response. Less than a partisan would claim and more than nothing. Survival of the seven staked tests would establish that a five-integer ledger reproduces the Standard Model’s parameters, the cosmological inventory, and a dark-matter line, with no fitted quantity — which is a fact about the world regardless of whether the two-fiber reading is the right explanation of it. The reading itself would remain a proposal, better supported and still not proved, with the entrance and the field-grade step still open. The author’s own view is that the honest ambition is to be *decided*, not to be believed.

Objection 117 (O-W2-117) (the referee, finally)

“What is the single strongest reason to take this seriously, in one sentence?”

Response. That one exact and elementary statement — holonomy requires closed loops, and an interval has none — was carried into twenty-two independently derived papers, entered each through its own central topic, required no value, grade, or theorem to change anywhere, and emerged with fifteen dated kill conditions. Whether that is a fact about the world or an unusually good piece of bookkeeping is not for the author to adjudicate, and the instruments now running will settle it either way.

83 What the hundred and seventeen leave standing

A tally is owed, because the point of collecting objections is not to appear to have survived them. Of the hundred and seventeen, several are conceded outright: this style of reasoning has misled physics before and the cases are named (Objection 47); the entrance to the corridor is a work order rather than a derivation; the field-grade representation step is open; the cap integer Ξ_{cap} is a benchmark and not yet a theorem; the $K/2$ exponent is postulated; the $4K$ family is arithmetic in search of a mechanism. A larger group is answered not by argument but by an instrument with a date — the tensor ratio, the haloscope line and its count, the neutrino phase, the lock resonance, proton decay, the equation of state. The remainder are answered structurally, and those are the ones where a reader is entitled to remain unconvinced: a structural answer is a claim about why a thing has the shape it has, and shapes are argued about.

What none of the hundred and seventeen does is ask the paper to be believed. Every result leaned on above is somebody's, and the references that follow say whose it is, what it cost the field to establish, and — where it matters — exactly where this paper's reading departs from the work it is built on.

Part XI

References

Cited Works, Each with a Relevance Note Linking It to the Present Paper

Unlike a conventional reference list, every entry below carries a full *Relevance* paragraph rather than a line of bibliographic courtesy. Each one says four things: what the cited work established, what it cost the field to establish it, how this paper reads that result on the two fibers, and — ending every note — exactly where in this paper the work is first cited, as a live cross-reference a reader can follow. The aim is to turn the bibliography from a bare list of sources into a navigable companion: a reader can move through the references and see, at a glance, which problem, equation, appendix, or figure each one underwrites, and jump straight to it.

The notes are written for two readers at once. For the newcomer, they trace the intellectual lineage of the sixteen problems: from Noether, Weyl, and Dirac, through the measurement debate, the gauge and renormalization revolutions, the discovery of the dark sector, and the black-hole information paradox, to the twenty-two-paper GG-Theory cohort whose results this paper synthesizes. Read end to end, Section B is a short history of the sixteen problems told through the papers that created them — and, in several cases, through the measurements that later closed a question the field had filed as interpretation. For the specialist, the notes make the paper’s debts explicit and checkable: each one names the specific claim it supports, so that no citation is merely decorative, and several say plainly where this paper’s reading departs from the cited work rather than building on it.

The references are organized in two groups: first the GG-Theory papers by the author (Section A), then all other works (Section B), each in the order in which the paper’s argument reaches them. The cohort papers are cited under the canonical keys fixed by the program’s cross-paper coherence map. Section B opens with the thematic works the anatomy leans on most directly, continues with the recommended textbooks of §60 — each annotated with the appendix it serves and the reason it is recommended over its rivals — and then follows the sixteen problems in order, from the measurement debate to the anthropic tradition. There are no orphan entries: every work listed is cited in the text, and every citation in the text resolves here.

A. Papers by Katsushi Arisaka (the GG-Theory cohort)

Arisaka, K. (2026). The GG-Constitution: Four Axioms and Seven Postulates of the GG-Theory Program, From Which GG-6, BI-6, OGN-5, and GDOS Descend as Theorems. Arisaka-GG-A1-Constitution.

Preprint, available at <https://preprints.arisaka-gg.org/a1-constitution/>.
doi:10.5281/zenodo.22063867.

Relevance. The charter of the program: four axioms and seven postulates from which everything here descends. AX-2 (GGEP) writes the two fibers — geometry and gauge structure as one composite object — and AX-3 (OGGEP) reads them, making observation a projection that marginalizes the fiber coordinates. This paper leans on it constitutively: the minimality argument of §16 is its two-fiber figure taken at its word; the census arguments of Problems 2, 7, and 15 rest on its forcing lemmas; MSMF, its parsimony clause, is what converts “no dials” from an aspiration into a law (Problems 4 and 6); and the grade vocabulary of §22 is its declared-conditioning discipline. First cited in the Executive Summary.

Arisaka, K. (2026). GG-Theory with GG-6: Geometry–Gauge Locking at the 6D Bulk (GG-6) at the Heart of Grand Geometric Theory (GG-Theory). Arisaka-GG-A2-GG6.

Preprint, available at <https://preprints.arisaka-gg.org/a2-gg6/>.

doi:10.5281/zenodo.22064298.

Relevance. The bulk paper: proves that the axioms force the arena (1) — the stage, the interval, and the circle — and derives the integer ledger $(M, N, L; J, K) = (1, 3, 5; 7, 35)$ with its closure identities $K = LJ$ and $J = 2N + 1$, and the dual-lock condition that selects N inside the anomaly audit (the audited chain Problem 6 spends). Its geometric-intuition Part carries the cohort’s original pair-read-together synthesis, of which this entire paper is the generalization; its forcing theorems are where the burden of Problem 15’s objection 4 (“you chose the interval”) is lawfully carried. First cited in §11.

Arisaka, K. (2026). Anomaly Freedom of BI-6: The Modified Bianchi Identity (BI-6) for the Six-Force, Six-Dimensional Bulk (GG-6). Arisaka-GG-A3-BI6.

Preprint, available at <https://preprints.arisaka-gg.org/a3-bi6/>.

doi:10.5281/zenodo.22064300.

Relevance. The anomaly paper: closes local and global anomaly freedom for the six-dimensional bulk by the Green–Schwarz mechanism, without supersymmetry, and in doing so fixes the ledger’s coefficient arithmetic — the locked vector $(1, -1, -\frac{2}{5}, -\frac{2}{5})$, the 5:2 trace ratio behind the Kaxion’s portals (Problem 7), and the dual-lock identity $L(2N + 1) = M^2 + N^2 + L^2$ that selects N , and through it J and K , from inside the audit (Problem 6). Problem 3’s central exhibit — anomaly coefficients as circle-side bookkeeping that cannot run — is its result, restated on the anatomy; the audit’s byproduct is the alphabet of integers every closed form in Problem 4 spends. First cited in Part II.

Arisaka, K. (2026). From Euclid to GG-6: The Realization of Euclid’s Elements in Six Dimensions — GU-5, OGN-5, and a Parameter-Free Reconstruction of Modern Physics. Arisaka-GG-A4-Euclid.

Preprint, available at <https://preprints.arisaka-gg.org/a4-euclid/>.

doi:10.5281/zenodo.22064302.

Relevance. The reconstruction paper: the five dimensionful constants (GU-5) derived as the conversion factors of the geometry’s directions — one per kind of dimension — and sorted by fiber: $\hbar$ the circle’s constant (the price of a tick), G_N the interval’s (the integrated warp volume, Problem 2’s gravity section), c the stage’s, k_B and Q_B the boundary’s. Problem 14’s closing section (why natural units are natural) is its closure theorem in plain English, and the character row of Table 4 is its pentad, aligned. First cited in §15.

Arisaka, K. (2026). GDOS: Geometric Dynamics of Open Systems — 6D GG-6 Bulk Projected to 4D Boundary for Quantum Measurement, General Relativity, and QFT. Arisaka-GG-A5-GDOS.

Preprint, available at <https://preprints.arisaka-gg.org/a5-gdos/>.

doi:10.5281/zenodo.22064304.

Relevance. The boundary-law paper: derives the open-system runtime (GDOS) whose generator is the interval’s semigroup — the projection that is always on, the memory-kernel reduction, complete positivity, and the textbook quantum postulates as theorems. This paper draws on it in every Part: the write of Problem 1 is its projection; the arrow of Problem 13 is its one-wayness; the two thermodynamic ledgers of Problem 14 (first law the circle’s, second the interval’s) are its currency theorems; and the KMS shore where temperature lives is its equilibrium analysis. First cited in Table 4.

Arisaka, K. (2026). The GRIP on GDOS — GRIP: the Geometric Engine of Symmetry Breaking, from the Big Bang to Mind. Arisaka-GG-A6-GRIP.

Preprint, available at <https://preprints.arisaka-gg.org/a6-grip/>.

doi:10.5281/zenodo.22064306.

Relevance. The runtime-engine paper: builds the four-pillar system and the GRIP cascade — $DGI \rightarrow GFF \rightarrow GSSB \rightarrow \text{attractor}$ — whose two regimes are the two fibers operating (GRIP-In the circle's stroke, GRIP-Out the interval's, §16) — completed, in its stage-custody subsection, by the finer transport-vs-data mapping: DGI's equivalences compose as the circle's group, the $GSSB \rightarrow GGA$ descent as the interval's semigroup, with the order parameters read from the circle and the outcome deposited back to it. Its Morse analysis supplies the unique-floor mechanism of the determinism triad (§18), on which Problems 8 and 15 lean — the uniqueness being Frankel–Atiyah's on the admissible strata its halting corollary names, and carried here at that grade; its identification of the weak interaction as the cascade realized in nature is Problem 2's agent section; and its attractor taxonomy (the GGA certificate) is the language of the trio's terminus. First cited in §16.

Arisaka, K. (2026). The Qi-4 Pillars — Qi-QUA, Qi-EP, Qi-CON, Qi-HAL: The Quantum-Information Backbone of GDOS. Arisaka-GG-A7-Qi4.

Preprint, available at <https://preprints.arisaka-gg.org/a7-qi4/>.

doi:10.5281/zenodo.22064308.

Relevance. The information pillar: memory on the circle (a stable bit as holonomy-class data), erasure on the interval (Landauer's bound as the one-way write's toll), and the Arisaka constant Q_B as the exchange rate between energy-per-winding and energy-per-qubit, fixed by ledger integers — the fourth currency of Problem 14. Problem 1's no-free-write kill condition is its audit; the record's cost accounting behind §36.9 is its theorem set. First cited in Problem 13.

Arisaka, K. (2026). Quantum Mechanics Derived from GG-Theory as Projection from 6D Bulk to 4D Boundary. Arisaka-GG-A8-QM.

Preprint, available at <https://preprints.arisaka-gg.org/a8-qm/>.

doi:10.5281/zenodo.22064310.

Relevance. The quantum-mechanics companion: locates the measurement arrow on the anatomy (§36.9) — the write as the runtime's record-forming face, decoherence as its microscopic face — and carries the Born chain at the relaxation level: the boundary law's own dissipation producing the Born measure, with the field-grade representation step the one named analytic residue. Problem 1 is, in essence, this paper's Part told in plain English, and the F25 relic that exposes it observationally is its prediction, carried by the cosmology companion. Inherited verbatim in the honest ledger. First cited in Problem 9.

Arisaka, K. (2026). The Standard Model as Theorem of GG-Theory: Its 28 Parameters as Observations of One Six-Dimensional Geometry. Arisaka-GG-A9-SM.

Preprint, available at <https://preprints.arisaka-gg.org/a9-sm/>.

doi:10.5281/zenodo.22064312.

Relevance. The codebook: all twenty-eight Standard-Model parameters derived or graded from the ledger, with the per-parameter provenance audit and honesty triage that Problem 4 summarizes and inherits. Its grammar — every parameter a holonomy-class label wearing a descent address — is this paper's most-quoted sentence; its closed forms ($\alpha^{-1}(0) = 2^J + N^2$, $\sin^2 \theta_W = L^2/(4N^3)$, $v = M_{\text{lock}}(2/L)^N$, the quark floors' winding-times-overlap form) anchor Problems 2, 4, and 6; and its treatment of why the weak interaction is special is Problem 2's agent section at full technical depth. First cited in §15.

Arisaka, K. (2026). The Standard Cosmology as Theorem of GG-Theory: The Cosmic Inventory as Observations of One Six-Dimensional Geometry. Arisaka-GG-A10-Cosmos.

Preprint, available at <https://preprints.arisaka-gg.org/a10-cosmos/>.

doi:10.5281/zenodo.22064314.

Relevance. The cosmology paper: the derived launch (the plateau class forced, $N^* = 52.6$, n_s , r), the terminus (the seesaw, $w = -1$ exactly, the de Sitter future), the chronology whose straight line is Figure 38,

the π -locked inventory with its honest Hopf resolution ($\Omega_m = 1/\pi$ as a fiber-volume ratio), the pinning mechanism with its zero-isocurvature signature, and the entrance as a named open item. Problems 5, 6, 7, and 8 are built on it; its “rolling, ringing, rest” synthesis is Problem 7’s parent; and the e-fold budget campaign it queues is the would-be closure of this paper’s entire flagged family. First cited in Problem 13.

Arisaka, K. (2026). The Geometric Inevitability of Cosmos, Life, and Mind: The Self-Referential Closure of the GG-Theory Program. Arisaka-GG-A11-Origin.

Preprint, available at <https://preprints.arisaka-gg.org/a11-origin/>.

doi:10.5281/zenodo.22064319.

Relevance. The capstone: traces the descent from the GUT edge to the biosphere through its cascade of attractors, and proves the GGA theorems (ground-state uniqueness, no-exit) — at the conditional grade §18 states for uniqueness — on which this paper’s attractor language rests — the electron’s identity, the terminus’s finality, and the Kaxion’s floor all cite it. The identity recursion of Problem 8 (sameness compounding from classes to chemistry to legibility) is its arc, compressed; its four words — not contingent, not lucky, not designed, forced — close this paper’s Conclusions. First cited in Part II.

Arisaka, K. (2026). The Kaxion: Cold Dark Matter as the Non-Spatial Compact-Angle Pseudoscalar of GG-6. Arisaka-GG-C1-Kaxion.

Preprint, available at <https://preprints.arisaka-gg.org/c1-kaxion/>.

doi:10.5281/zenodo.22064333.

Relevance. The dark-matter paper: the Kaxion’s existence theorem (two compact parents, one light eigenstate), the GRIP birth on the compact-angle stratum, and the full two-fiber portrait — matter of the circle, occupancy of the interval — of which Problem 7’s middle panel is the condensation. Every Kaxion number here is its: $8.1 \mu\text{eV}$, 1.95 GHz , the discrete cap window with its base rung at $\Xi_{\text{cap}} = K$, the count, the strong-CP alignment (Problem 12’s dissolution), and the identify-by-the-circle search strategy. Its one open integer (Ξ_{cap}) is carried in the honest ledger. First cited in Part II.

Arisaka, K. (2026). The Hubble Tension in the Light of GG-Theory: The Hubble Constant as One Reading of a Derived Expansion History $H(t)$. Arisaka-GG-C2-Hubble.

Preprint, available at <https://preprints.arisaka-gg.org/c2-hubble/>.

doi:10.5281/zenodo.22064336.

Relevance. The Hubble paper: derives the expansion history from the inventory with no dial — cooling is descent, $d \ln t / dr = 2$, $H = 1/(2t)$ in the radiation era — and reads the Hubble tension as two dictionaries meeting at the corridor. This paper quotes it wherever the clock meets the laboratory: the odometer remark of §36.4 (three clocks and one odometer), the chronology’s slope in Problem 13, and the repricing answer to Problem 14’s expanding-universe question. First cited in Problem 13.

Arisaka, K. (2026). Black-Hole Entropy under GG-Theory: The GDOS Reading of the Horizon as an OGGE Port — with the Exact Bekenstein–Hawking $A/4G_N$ Derived from Induced Gravity. Arisaka-GG-C3-BH.

Preprint, available at <https://preprints.arisaka-gg.org/c3-bh/>.

doi:10.5281/zenodo.22064338.

Relevance. The black-hole paper: the information paradox resolved as a billing error — the circle keeps what the hole must return; the interval prices the return — with the Page curve as the two books’ reconciliation schedule, no firewalls, and the island computations placed with their achievements intact. Problem 16 is its treatment carried whole into this paper’s register, including the de Sitter cousin that ties the paradox to the trio’s terminus. Cited in Part VII’s contrasts and throughout Problem 16. First cited in §26.6.

Arisaka, K. (2026). The GG-6 Lock Cluster: A Non-Spatial Kaluza–Klein Resonance near 3.85 TeV as the Standing LHC Falsifier of GG-Theory. Arisaka-GG-P1-KK.

Preprint, available at <https://preprints.arisaka-gg.org/p1-kk/>.

doi:10.5281/zenodo.22064321.

Relevance. The collider paper: the Kaluza–Klein lock cluster at 3.849 TeV as a zero-parameter target — one mass, one width, one rate, one interference sign, one angular shape, one branching fingerprint, with a dated decision calendar. It is this paper’s sharpest single kill switch (Problems 2 and 6 both stake it), and its two-fiber reading — a discovery as a double reading, identity from the circle and address from the interval — is the laboratory twin of the Kaxion’s haloscope strategy at the opposite end of the energy ladder. First cited in §23.3.

Arisaka, K. (2026). Why Three Generations: A Three-Leg Derivation of $N_g = 3$ from BI-6, MSMF, and GDOS Morse Stability. Arisaka-GG-P2-N3.

Preprint, available at <https://preprints.arisaka-gg.org/p2-n3/>.

doi:10.5281/zenodo.22064323.

Relevance. The family-number paper: $N_g = 3$ closed with explicit lower and upper bounds inside one declared axiom system — the count written on the circle (holonomy-class, unable to run), the capacity bound priced by the interval (a budget being a semigroup concept). It is the methodological twin of every exactness claim in this paper, and Problem 12’s why-three-colors section leans on its pincer: two derivations sharing no premise, one small integer. Its Appendix H is the cohort’s formal proof of the sentence this paper uses as a refrain — *what the circle quantizes is what the interval delivers* — the two-sided audit behind the ledger’s permanence in Problems 3, 4 and 12: the bulk with its anomaly ledger and compact directions, and the boundary with its adiabatic theorem, computing the same object independently and with no shared parts. Cited in Part VII. First cited in §23.3.

Arisaka, K. (2026). The Electron as the Ground State of Nature: The Six Oldest Questions about the Electron, Closed and Fenced within GG-Theory. Arisaka-GG-P3-Electron.

Preprint, available at <https://preprints.arisaka-gg.org/p3-electron/>.

doi:10.5281/zenodo.22064325.

Relevance. The electron paper: identity and stability as ground-state theorems — every electron the same readout of the same attractor, unique at the grade §18 states — and the first portrait in the triptych: *a holonomy class wearing a mass*, the sentence Problems 10, 7, and 14 generalize. The mirror reading of the positron (same class, conjugate orientation, same address) is Problem 10’s opening; the muon’s descent rate as a GRIP-In observable times Problem 2’s agent. First cited in Problem 10.

Arisaka, K. (2026). The Real Geometry Beneath the Complex Numbers of Physics: Positive Frequency is Holomorphy — from Cardano’s Cubics to Twistor Space, via the Sixth Dimension of GG-Theory. Arisaka-GG-P4-Real.

Preprint, available at <https://preprints.arisaka-gg.org/p4-real/>.

doi:10.5281/zenodo.22064327.

Relevance. The real-bulk paper: derives quantum mechanics’ complex structure from two real sources — the phase circle and the constitutional clock — with the discrete-symmetry table generated by their orientations (Problem 9’s calculus), the antiparticle pairing forced by their handshake (Problem 10), antiunitarity of T as an orientation corollary, and the custody principle — the dictionary owns the sectors; the geometry owns the i — behind Problem 1’s records-are-real clause. The network Bell exclusion of real-valued quantum mechanics is its one indispensable experimental fact. First cited in Part II.

Arisaka, K. (2026). The Mirrors of Matter: Why Every Particle Has a Twin, Why Nature’s Mirrors Break, and Why the Universe Is Made of Matter. Arisaka-GG-P5-CPT.

Preprint, available at <https://preprints.arisaka-gg.org/p5-cpt/>.
doi:10.5281/zenodo.22064329.

Relevance. The CPT companion and this paper’s largest single creditor — the parent of Problems 9, 10–11, and 13. From its Part on the birth of matter: the alphabet audit (bystander, spectator, inert, driver), the gated crossing, and the η_B chain with its named input, named regulator, and postulated $K/2$ exponent. From its Part on time: the four endowments, the exact slope, the age ledger closing at 140.24, the clock ladder, and the two-quantity discipline at recombination. Its KMS shore — temperature as where the interval meets the shore — recurs in Problems 14 and 16. First cited in §23.3.

Arisaka, K. (2026). The Proton as the Ground Geometric Attractor of Matter: The Eleven Questions of the Proton, Closed and Fenced within GG-Theory. Arisaka-GG-P6-Proton.

Preprint, available at <https://preprints.arisaka-gg.org/p6-proton/>.
doi:10.5281/zenodo.22064331.

Relevance. The proton paper and Problem 12’s parent: confinement as the registration rule (only closed color books reach the boundary), the abelian ledger with its double guard — $Q + t/3 \in \mathbb{Z}$ and $Q + B \in \mathbb{Z}$, verified fragment by fragment across the hadron zoo with the $\mathbb{Z}_6$ quotient checked trivial — and the welded sphaleron door that seals Problem 11’s excess into permanent storage. The second portrait of the triptych (two holonomy ledgers wearing a weld) is its; the biosphere-underwriting argument of Problem 12 runs on its stability theorems. First cited in §23.3.

Arisaka, K. (2026). Symmetry, Conservation, and Geometry: Seven Steps from Noether, Bianchi, to Hopkins–Singer, and the Ledger the Open-System Turn Pays Out. Arisaka-GG-W1-Symmetry.

Preprint, available at <https://preprints.arisaka-gg.org/w1-symmetry/>.
doi:10.5281/zenodo.22064340.

Relevance. The first white paper and this one’s sibling — diachronic where this paper is synchronic (§43). Its seven-step arc from Noether to Hopkins–Singer supplies Problem 3’s foundations (the second theorem, Elitzur, the Wilson turn); its capstone — symmetry breaking as symmetry reading, with the determinism triad — is §18 and the engine of Problems 8 and 15; and its four closing words are this paper’s as well. The campaign whose cohort-wide deployment this paper consolidates began in its pages. First cited in the Executive Summary.

B. Other references

E. Noether. *Invariante Variationsprobleme*, Nachr. Ges. Wiss. Göttingen (1918) 235.

Relevance. The paper that made symmetry a computational instrument rather than an aesthetic observation, and it did so twice. The first theorem converts a continuous global symmetry into a conserved current, which is where the tick of Problem 13 acquires its conservation law; the second converts a *local* symmetry into identities among the equations of motion — not new conservation laws but constraints, which is the technical root of the statement in Problem 3 that a gauge symmetry is a redundancy rather than a property of the world. The distinction between the two theorems is the distinction this paper’s anatomy makes geometric: the first theorem’s symmetries live where a closed loop can be traversed and a phase compared, the second theorem’s redundancies are the price of describing that loop in coordinates. GG-W1-Symmetry traces the whole arc from this paper to the Hopkins–Singer integers; this paper enters that arc at its geometric end and reads Noether’s two theorems as the two fibers’ two jobs. First cited in §3.3.

P. A. M. Dirac. *Quantized singularities in the electromagnetic field*, Proc. R. Soc. A **133** (1931) 60.

Relevance. The origin of every protected integer in physics. Dirac showed that the mere consistency of a charged quantum particle in the field of a magnetic monopole forces $eg = n\hbar c/2$ with n an integer — the first demonstration that an exact quantization can follow from topology rather than from a dynamical equation, and hence the ancestor of every closed form on the circle side of this paper’s anatomy. The same paper proposed the anti-electron, which makes it the founding document of Problems 10–11 as well. What this paper takes from it is the argument’s shape rather than its content: an integer that cannot vary continuously has nowhere to move to, which is why circle-side quantities in the ledger $(M, N, L; J, K)$ do not run and cannot be dialed (Problem 4). Dirac’s own comment that the argument explains charge quantization “if a single monopole exists anywhere” is the historical model for the cohort’s habit of paying for exactness with a topological hypothesis rather than a fitted parameter. First cited in §5.2.

A. D. Sakharov. *Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe*, JETP Lett. **5** (1967) 24.

Relevance. Three conditions — baryon-number violation, C and CP violation, and departure from thermal equilibrium — without which no dynamical mechanism can produce a matter–antimatter asymmetry from a symmetric start. Sakharov’s list has organized every baryogenesis proposal for half a century, and its persistence is precisely the difficulty of Problems 10–11: the conditions are necessary, they are individually achievable, and the Standard Model satisfies all three too weakly by ten orders of magnitude. This paper reads the list as an anatomy statement rather than a checklist: the first two conditions are circle-side questions about what the phase structure permits, the third is an interval-side question about whether the descent is fast enough that the composition has no inverse. That the three conditions sort cleanly onto the two fibers is one of the paper’s recurring pieces of evidence that the sorting is doing real work. First cited in §5.2.

M. Kobayashi and T. Maskawa. *CP-violation in the renormalizable theory of weak interaction*, Prog. Theor. Phys. **49** (1973) 652.

Relevance. The observation that CP violation in the quark sector requires at least three generations, because only then does the mixing matrix retain a physical complex phase after all rephasings are exhausted. It is a counting argument of exactly the kind this paper’s census sections use, and it earned its authors the Nobel Prize when the third family duly appeared. The Kobayashi–Maskawa phase is also the reason Problems 10–11 are hard rather than merely unsolved: the phase exists, it is measured, and [Gavela et al. \(1994\)](#) showed that the asymmetry it can generate falls short of the observed value by some ten orders of magnitude. In this paper’s reading the quark phase is a chiral bystander — a genuine circle-side phase that is nevertheless not the one that pays the toll — and the leptonic phase of the cohort’s pentagon is. First cited in §5.1.

M. Fukugita and T. Yanagida. *Baryogenesis without grand unification*, Phys. Lett. B **174** (1986) 45.

Relevance. Leptogenesis: the proposal that the baryon asymmetry is manufactured first as a lepton asymmetry, in the CP-violating out-of-equilibrium decays of heavy right-handed neutrinos, and then converted to baryon number by electroweak sphalerons ([Kuzmin et al., 1985](#)). It has become the leading mechanism precisely because it recycles machinery introduced for another purpose — the seesaw that makes the light neutrinos light — rather than adding new sectors. The standing difficulty, and the reason Problems 10–11 remain open, is that the mechanism is a framework with free parameters rather than a prediction: the heavy masses and phases are not measured. This paper’s interest is in the geometric realization the cohort supplies, in which the phases are ledger objects rather than inputs, so that the toll acquires a computed value ($\eta_B \approx 7 \times 10^{-10}$, central 7.34, +20% from the measured number inside its factor- ~ 3 band) with its one postulated exponent flagged in place. First cited in §5.2.

K. G. Wilson. *Confinement of quarks*, Phys. Rev. D **10** (1974) 2445.

Relevance. The paper that put gauge theory on a lattice and, in doing so, identified the gauge-invariant content of the theory as the set of holonomies around closed loops. Wilson’s area law for the loop expectation value in the strong-coupling limit is still the cleanest statement of what confinement *means*, and his reconstruction — the field is recoverable from its loop functionals — is the technical fact behind this paper’s central sentence. When §11 says that holonomy requires closed loops, it is Wilson’s variables that make the requirement more than a definition: they are what a gauge theory is made of, and an open interval supplies none of them. Problem 12’s treatment is built on the same foundation, with the $\mathbb{Z}_3$ center read as a winding label on the circle and the registration rule written as a projection selection rule. First cited in §5.3.

ATLAS Collaboration. *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. B **716** (2012) 1.

Relevance. One of the two discovery papers for the scalar at 125 GeV. It is cited in §24 for what it retired rather than for what it found: a generation of model-building had rested on the structural instinct that an elementary scalar cannot exist because nothing protects its mass, and the instinct was wrong. This paper’s own account of the electroweak scale as a holonomy-placed address is a structural argument of the same genre run in the opposite direction, which is why the episode is printed here rather than omitted. First cited in §24.

CMS Collaboration. *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys. Lett. B **716** (2012) 30.

Relevance. The independent confirmation, on a different detector with different systematics, of the particle reported by ATLAS in the same issue. Cited alongside it in §24 because the honest-record argument turns on the falsification being beyond dispute. First cited in §24.

Hatanaka, H., Inami, T. & Lim, C. S. (1998). The gauge hierarchy problem and higher-dimensional gauge theories. *Mod. Phys. Lett. A*, **13**, 2601.

Relevance. The result that makes §27.8’s tier 2 a theorem rather than a hope: the effective potential of a Wilson-line phase is finite, because no local counterterm for such a phase exists. This paper’s account of why the electroweak scale is placed rather than tuned is inherited from this line of work and is not claimed as new; what the anatomy adds is the classification — that the electroweak sector’s selector is the circle’s one continuous modulus, and that the naturalness problem is the error of reading the scale that selector places as an interval-side accident. The theorem is about the phase, and the cohort does not extend it to the doublet (§27.8). First cited in §27.8.

Y. Hosotani. *Dynamical mass generation by compact extra dimensions*, Phys. Lett. B **126** (1983) 309.

Relevance. The mechanism by which a gauge field’s Wilson line around a compact extra dimension acquires a vacuum expectation value and breaks the gauge symmetry — symmetry breaking with no elementary scalar, driven purely by the holonomy of a circle. It is the most direct precedent in the literature for the reading this paper generalizes: a physical, measurable vacuum label that is a holonomy and nothing else, protected against local corrections because it is not a local quantity — the tier-2 protection of §27.8. Problem 2’s account of why the four interactions look so unlike leans on it directly: the circle’s Wilson-line label is what sets the electroweak address, while the interval’s warp sets the scale, and the apparent dissimilarity of the forces is the two fibers doing two different jobs at once. The historical lesson — that a compact direction can supply a vacuum structure a four-dimensional theory would have to postulate — is one this paper repeats in six other places. First cited in §26.4.

M. B. Green and J. H. Schwarz. *Anomaly cancellations in supersymmetric $D = 10$ gauge theory*, Phys. Lett. B **149** (1984) 117.

Relevance. The anomaly-cancellation mechanism that made ten-dimensional string theory viable: a two-form field whose modified Bianchi identity $dH_3 = X_4$ absorbs an otherwise fatal anomaly, at the cost of a rigid relation among the theory's group-theoretic coefficients. This paper cites it for the mechanism rather than the setting. GG-A3-B16 constructs the six-dimensional, non-supersymmetric instance in which the same identity closes local and global anomaly freedom for the bulk $\mathcal{M}_4 \times I_r \times S^1_\theta$, and it is that closure which fixes the coefficient arithmetic every closed form in Problem 4 spends. The general moral is the one Problem 3 draws on the anatomy: anomaly coefficients are integers computed by a topological index, they are therefore circle-side objects, and quantities of that kind do not run with scale — which is why the cancellation is a constraint on the theory rather than a condition to be maintained order by order. First cited in §12.1.

M. J. Hopkins and I. M. Singer. *Quadratic functions in geometry, topology, and M-theory*, J. Diff. Geom. **70** (2005) 329.

Relevance. The mathematical terminus of GG-W1-Symmetry's arc: differential cohomology, in which a quantity can be protected by an integer invariant with no symmetry group anywhere in sight. The paper matters here as an existence proof for a category this framework needs — exactness that is not Noetherian — and as the reason the cohort's language distinguishes *protected* from *conserved*. A conserved quantity is the output of a symmetry and can be spoiled by breaking it; a protected quantity is the output of a topological classification and can only change by a discontinuous jump that the geometry forbids. That distinction is the whole content of the circle side of this paper's anatomy, and the two white papers are shown there to be reading the same structure from opposite ends. First cited in §43.

C. Conley. *Isolated Invariant Sets and the Morse Index*, CBMS Regional Conference Series in Mathematics **38**, American Mathematical Society (1978).

Relevance. The fundamental theorem of dynamical systems: every continuous flow on a compact metric space carries a complete Lyapunov function. The first of the four levels at which the landscape of §18 is a Lyapunov function, and the one that owes nothing to the geometry. First cited in §18.

G. Lindblad. *Completely positive maps and entropy inequalities*, Commun. Math. Phys. **40** (1975) 147.

Relevance. Relative entropy is non-increasing under any completely positive map, so the relative entropy to a stationary state descends under any open quantum dynamics: the second level of §18, and the theorem behind the Born chain's relaxation in Appendix 64. First cited in §18.

H. Spohn. *Entropy production for quantum dynamical semigroups*, J. Math. Phys. **19** (1978) 1227.

Relevance. The entropy production of a quantum dynamical semigroup with a stationary state is non-negative; cited with Lindblad for the identity of the descending function as the relative entropy. First cited in §18.

T. Frankel. *Fixed points and torsion on Kähler manifolds*, Ann. Math. **70** (1959) 1.

Relevance. The Morse indices of a moment-map component on a compact Kähler manifold are even, so the function is perfect and a connected stratum has one floor. The theorem that makes the determinism triad's floor unique on admissible strata (§18); the condition an earlier statement of this paper misnamed as strict Morse positivity. First cited in §18.

M. F. Atiyah. *Convexity and commuting Hamiltonians*, Bull. London Math. Soc. **14** (1982) 1.

Relevance. The level sets of a moment-map component are connected, which extends Frankel's uniqueness of the floor to the case where the floor is a manifold rather than a point. First cited in §18.

A. H. Guth. *Inflationary universe*, Phys. Rev. D **23** (1981) 347.

Relevance. The paper that turned three separate cosmological embarrassments — the horizon problem, the flatness problem, and the monopole problem — into one dynamical proposal: a period of accelerated expansion early enough to place today’s causally disconnected patches inside one past light cone. Its success is not in dispute here; Problem 5 accepts the necessity of an inflationary epoch and its evidence, and Problem 8’s account of why distant strangers agree is inflation’s account. What Problem 5 disputes is the *menu*: after four decades the mechanism remains a class of models with hundreds of members and no principle selecting one, so that inflation predicts the pattern but not the parameters. This paper’s contribution is to let the census decide — one non-compact non-spatial coordinate is permitted, hence one field of the relevant kind — so that the potential’s shape follows from the warp rather than from a choice. First cited in §4.1.

A. D. Linde. *A new inflationary universe scenario*, Phys. Lett. B **108** (1982) 389.

Relevance. The new inflationary scenario, which rescued Guth’s proposal from its graceful-exit problem by having the field roll slowly along a flat plateau rather than tunnel out of a false vacuum. Slow roll is what makes inflation calculable: the spectral observables become derivatives of the potential, and a model becomes a prediction. It is also, on this paper’s reading, the clearest dynamical portrait of what an interval traverse *is* — a motion along a non-compact direction, damped by Hubble friction, that happens once and does not return. Problem 5 identifies the field doing the rolling with the interval’s own position coordinate, which is why the framework has one inflaton rather than a choice of inflatons, and why N^* becomes a length rather than a fitted number. First cited in §4.1.

A. A. Starobinsky. *A new type of isotropic cosmological models without singularity*, Phys. Lett. B **91** (1980) 99.

Relevance. The original inflationary solution, predating the word: a de Sitter phase driven by the R^2 correction to the gravitational action, decaying into radiation. Its potential, written in the Einstein frame, is the plateau whose spectral predictions — a red tilt near $n_s \simeq 0.96$ and a small tensor ratio — the data have since favored over every competitor with a steep potential. This paper cites it as the shape rather than the model: the GDOS anomaly argument forces a plateau class, and Eq. (31)’s parent potential is a member of it. The discriminating claim in Problem 5 is not the tilt, on which many models agree, but the pair (n_s, r) read from a *derived* $N^* = 52.6$, which fixes $r = 0.0038$ with nothing left to adjust. First cited in §4.1.

R. D. Peccei and H. R. Quinn. *CP conservation in the presence of pseudoparticles*, Phys. Rev. Lett. **38** (1977) 1440.

Relevance. The proposal that the strong CP problem is solved by a new global symmetry, broken spontaneously, whose associated angle relaxes dynamically to zero. Together with Weinberg (1978) and Wilczek (1978) — who pointed out that the broken symmetry leaves a light pseudoscalar behind — it created the axion, and with it the most economical dark-matter candidate in the literature. The unsolved part, and the reason Problem 7 is still a problem, is the decay constant: the mechanism fixes the axion’s mass only once f_a is chosen, and nothing in the construction chooses it. The cohort’s Kaxion is the same object with the choice removed — $f_K = f_{\text{bulk}}/\Xi_{\text{cap}}$ with $\Xi_{\text{cap}} = K + N + L = 43$ — which converts a parametrized family into a single line at $8.1 \mu\text{eV}$ (1.95 GHz) inside a window of seven computed rungs. First cited in §4.3.

J. Preskill, M. B. Wise, and F. Wilczek. *Cosmology of the invisible axion*, Phys. Lett. B **120** (1983) 127.

Relevance. The relic-abundance calculation that made the invisible axion a dark-matter candidate rather than a curiosity: the misalignment mechanism, in which the field begins at a random angle, stays frozen until $3H \simeq m_a$, and then oscillates as pressureless matter whose density scales as a^{-3} . The calculation is the template Problem 7 follows exactly — the oscillation condition, the entropy dilution, the initial-angle

dependence — and its structure is why the abundance is predictive only once f_a is fixed. This paper’s interest is that every input to the calculation except the misalignment angle becomes a ledger quantity in the cohort’s treatment, so the surviving uncertainty is astrophysical rather than parametric. First cited in §4.3.

S. Weinberg. *The cosmological constant problem*, Rev. Mod. Phys. **61** (1989) 1.

Relevance. The review that fixed the cosmological-constant problem in its modern form, cataloged the failed approaches, and stated the discrepancy with a precision that has embarrassed the field ever since: the vacuum energy estimated from quantum field theory exceeds the observational bound by some 120 orders of magnitude, and no symmetry known will set it to zero without setting it to zero exactly. Weinberg’s own survey of mechanisms — adjustment, symmetry, anthropic selection — is the map of the territory Problem 6 and Problem 15 traverse. This paper’s position is stated as a repricing rather than a solution: the loop’s reach is bounded by the same e^{-K} that sets the lock scale, the residual scale $m_\Lambda = M_{\text{lock}}^2/M_{\text{Pl,red}} = 6.1 \text{ meV}$ is computed rather than canceled, and the master table grades that row *repriced*, not *solved*. First cited in §4.2.

A. G. Riess et al. *Observational evidence from supernovae for an accelerating universe*, Astron. J. **116** (1998) 1009.

Relevance. One of the two supernova surveys that discovered the acceleration of the cosmic expansion, and with it the observational necessity of a dark-energy component. The measurement converted the cosmological constant from a problem of principle — why is it not enormous? — into a problem of value: why is it small but not zero, and why is it comparable to the matter density now? Problem 6 quotes the result for the second question, which is the harder one, and Problem 15 quotes it against Weinberg (1987): the anthropic bound was an upper limit some two orders of magnitude above what was subsequently measured, so the measurement neither confirms nor refutes the selection argument. This paper’s inventory instead computes the shares directly, with $\Omega_m = 1/\pi$ and $\Omega_\Lambda = 1 - 1/\pi$ as fiber-volume ratios. First cited in §4.2. First cited in §4.

S. Perlmutter et al. *Measurements of Ω and Λ from 42 high-redshift supernovae*, Astrophys. J. **517** (1999) 565.

Relevance. The companion supernova survey, independent in team, instrument, and analysis chain, reaching the same conclusion from 42 high-redshift objects. The pair is cited together throughout Part I because the agreement of two independent measurements is what made the acceleration credible immediately rather than after a decade — a methodological point this paper makes repeatedly about its own two-route derivations (Problem 6’s ledger, Problem 12’s $N = 3$). What the surveys established is the target the cohort’s inventory has to hit, and the honesty discipline of §22 requires the distinction to be kept visible: the framework’s closed forms are compared against these numbers, not fitted to them. First cited in §4.2.

Planck Collaboration. *Planck 2018 results. VI. Cosmological parameters*, Astron. Astrophys. **641** (2020) A6.

Relevance. The cosmological parameters from the full Planck mission — the reference dataset against which every quantitative claim in Problems 5–8 is checked. The paper is cited for the inventory shares, the spectral index, the tensor bound, the acoustic scale, and the decoupling redshift, and it is the source of the numbers that make the cohort’s closed forms falsifiable rather than decorative. Two of the paper’s disciplines are visible in how it is used. First, the *two-quantity* z^* convention: the corridor switch $z_{\text{sw}} = e^7 = 1096.6$ is a topological quantity of the framework, while the atomic decoupling redshift $z_{\text{dec}} \approx 1090$ is the measured quantity Planck reports, and the two must never be conflated even though they agree to a fraction of a percent. Second, the raw-versus-calibrated distinction: agreements are quoted in both registers, with the zero-parameter number given first. First cited in §4.1.

G. W. Gibbons and S. W. Hawking. *Cosmological event horizons, thermodynamics, and particle creation*, Phys. Rev. D **15** (1977) 2738.

Relevance. The extension of black-hole thermodynamics to cosmological horizons: de Sitter space has a horizon, the horizon has a temperature and an entropy, and an observer inside sees thermal radiation with no matter present anywhere. It is the result that makes the accelerating universe a thermodynamic object and ties Problem 16 to Problem 6 — the same horizon-entropy bookkeeping that governs a black hole governs the terminus of the cosmic descent. This paper uses it at the end of Problem 16 to place the information question in its cosmological setting: if a horizon spends $\hbar$, G_N , and k_B at once, the accounting cannot be a property of collapsed stars in particular, and the two-fiber reading has to work at both ends of the descent or at neither. First cited in §39.

M.-O. Renou et al. *Quantum theory based on real numbers can be experimentally falsified*, Nature **600** (2021) 625.

Relevance. The theoretical result that quantum theory formulated over the real numbers is not merely inelegant but experimentally distinguishable from the standard complex theory — a Bell-type scenario in which the two formulations predict different correlations. It is cited here for a methodological reason that matters to this paper’s whole enterprise: a question that had been treated for ninety years as interpretational was converted into a measurement. The framework’s own claim about the origin of the imaginary unit — the custody principle, in which the dictionary owns the sectors and the geometry owns the i — sits in exactly this category, which is why the episode is used to explain what this paper means by a falsifiable structural claim. The subsequent experimental exclusions are [Li et al. \(2022\)](#) and [Chen et al. \(2022\)](#). First cited in §2. First cited in §2.

K. G. Wilson and J. Kogut. *The renormalization group and the ϵ expansion*, Phys. Rep. **12** (1974) 75.

Relevance. The review that made the renormalization group a picture rather than a technique: couplings flowing under a change of resolution, fixed points organizing the flow, and irrelevant operators dying out — the modern understanding that a quantum field theory is a trajectory rather than a point. This is the single most important external input to Problem 3, because the flow it describes is, on this paper’s anatomy, a motion along the interval. Kadanoff blocking composes forward and has no inverse; the information discarded at each step is not recoverable; the flow is therefore a semigroup, and $\partial_r = -\mu\partial_\mu$ identifies the scale direction with the interval’s coordinate. What the framework adds is endpoints: an interval has two, so the flow has a beginning and an end rather than running forever in both directions. First cited in §3.3.

J. P. Lees et al. (BaBar Collaboration). *Observation of time-reversal violation in the B^0 meson system*, Phys. Rev. Lett. **109** (2012) 211801.

Relevance. The first direct observation of time-reversal violation as such — not inferred from CP violation plus the CPT theorem, but measured by comparing the rates of B^0 transitions in one time order against the reverse, using entangled meson pairs to prepare the initial states. It matters to Problem 9’s account for a reason of logical hygiene: with this measurement in hand, all three of C, P, and T are known experimentally to fail individually, and the survival of the combination CPT is a separate, independently checked fact rather than a definitional convenience. That is exactly the shape of the anatomy’s claim — three orientations that a bundle can reverse individually, one total orientation that it cannot — so the experimental record and the geometric statement are testing the same structure. First cited in §5.1.

M.-C. Li et al. *Testing real quantum theory in an optical quantum network*, Phys. Rev. Lett. **128** (2022) 040402.

Relevance. One of the two 2022 experiments that closed the real-quantum-theory question opened by [Renou et al. \(2021\)](#), ruling out the real-valued formulation in an optical quantum network. Cited alongside [Chen et al. \(2022\)](#) as the completion of the episode: a structural question about the mathematical furniture

of the theory — whether the complex numbers are essential or merely convenient — moved from philosophy to laboratory in under two years. The paper holds this up as the standard its own structural claims should be held to, and the falsifier table of §48 is the attempt to meet it. First cited in §2.

M.-C. Chen et al. *Ruling out real-valued standard formalism of quantum theory*, Phys. Rev. Lett. **128** (2022) 040403.

Relevance. The companion exclusion of real-valued quantum theory, performed on a superconducting processor, independent of Li et al. (2022) in platform and systematics. The pair is cited together for the same reason the two supernova surveys are: two independent instruments reaching one conclusion is what converts a result into a fact. In this paper’s use, the episode supplies the template for how a claim about structure — rather than about a value — can be made to face an instrument, which is the methodological demand made of the sixteen problem treatments that follow. First cited in §2.

M. Arndt, O. Nairz, J. Vos-Andreae, C. Keller, G. van der Zouw, and A. Zeilinger. *Wave-particle duality of C_{60} molecules*, Nature **401** (1999) 680.

Relevance. The fullerene interferometry experiment: C_{60} molecules, roughly a kilodalton of mass and seventy nuclei, sent through a grating and observed to interfere. It is the standing benchmark for how large an object can be and still show its wave nature, and it is cited in Problem 1 as the empirical anchor of the decoherence account — above this scale the environmental monitoring rate exceeds any achievable coherence time, and the wave nature becomes operationally inaccessible rather than absent. The experiment matters to this paper’s reading because it shows the transition is quantitative and continuous, set by a rate, not by a boundary between two kinds of matter: the interval’s irreversible composition is doing more of the work as the object grows, and nothing switches on. First cited in §25.

R. Landauer. *Irreversibility and heat generation in the computing process*, IBM J. Res. Dev. **5** (1961) 183.

Relevance. The result that erasing one bit of information costs at least $k_B T \ln 2$ of dissipated heat — the first quantitative bridge between information and thermodynamics, and the resolution of Maxwell’s demon once the demon’s memory is included in the accounting. Problem 14 uses it as the pivot of the whole treatment: entropy is not an analogy for missing information but the same quantity, and the cost is charged at the moment of *erasure*, that is, at the moment a many-to-one map is applied. On this paper’s anatomy that is the interval’s signature — a composition with no inverse — which is why the demon is closed by the same structure that supplies the arrow of Problem 13 rather than by a separate argument. First cited in §6.2.

M. B. Gavela, P. Hernández, J. Orloff, and O. Pène. *Standard model CP-violation and baryon asymmetry*, Mod. Phys. Lett. A **9** (1994) 795.

Relevance. The calculation that quantified the shortfall: with the Kobayashi–Maskawa phase as the only source of CP violation, the baryon asymmetry generated at the electroweak transition falls below the observed value by roughly ten orders of magnitude. It is the reason Problems 10–11 are hard rather than merely unfinished — the Standard Model satisfies all three Sakharov conditions and still fails, so the deficit is quantitative and cannot be argued away. This paper cites it as the size of the debt any proposal must actually pay, and as the reason the cohort’s account routes the asymmetry through the leptonic phase rather than the quark phase: the quark phase is measured, its contribution is computed, and it is not enough. First cited in §5.2.

R. M. Wald. *General Relativity*, University of Chicago Press (1984).

Relevance. The standard graduate text on general relativity, and the one this paper recommends for the geometric machinery rather than for the applications: manifolds, connections, curvature, and the causal structure of spacetime developed with the care a reader of Appendix A will need. Its treatment of

Killing vectors and stationarity is the background for the appendix’s discussion of what a static arena buys, and its chapters on horizons and black-hole thermodynamics underwrite Appendix I’s four laws. Wald is recommended over its rivals for this paper’s purposes because it is uncompromising about the distinction between a structure that exists on a manifold and a structure that exists only in a chart — the very distinction the two-fiber reading turns into physics. First cited in §60.

D. Baumann. *Cosmology*, Cambridge University Press (2022).

Relevance. The modern graduate cosmology text, written by an inflationary theorist, and the reference of first resort for Appendices E and F. Its derivations of the Friedmann equations, the thermal history, the horizon problem, slow roll, and the mode-freezing origin of the primordial spectra are the ones Appendix E’s Step 1 follows in structure, and its treatment of the CMB transfer functions is what a student needs before the inventory comparisons of Problem 7 will make sense. It is recommended first among the cosmology texts because it is the most recent and the most explicit about which parts of the standard story are measured and which are modeled — a distinction this paper’s grade vocabulary depends on. First cited in §60.

S. Weinberg. *Cosmology*, Oxford University Press (2008).

Relevance. Weinberg’s cosmology, recommended for the analytic backbone that the more pedagogical texts compress: the perturbation theory done in full, the transfer functions derived rather than quoted, and the anisotropy calculation assembled from first principles. Appendix E cites it where a reader wants to see the machinery rather than the result, and Problem 6’s discussion of the vacuum-energy problem quotes its framing alongside Weinberg (1989). The book is also useful here as a model of tone: it is scrupulous about the difference between what the standard framework derives and what it accommodates, which is the discipline the honest ledger of §47 tries to keep. First cited in §60.

E. W. Kolb and M. S. Turner. *The Early Universe*, Addison-Wesley (1990).

Relevance. The early-universe reference: thermal history, relic abundances, freeze-out, entropy accounting, and the g_* counting that Appendix E’s reheating discussion and Appendix F’s relic-density derivation both use. It remains the cleanest source for the calculation Problem 7’s Kaxion abundance follows step for step — the oscillation condition, the comoving number density, the entropy dilution — and for the effective-degrees-of-freedom tables the descent’s e-fold accounting requires. Its age shows in the data it quotes and nowhere else; the machinery is unchanged. First cited in §60. First cited in §60.

J. J. Sakurai and J. Napolitano. *Modern Quantum Mechanics*, 3rd ed., Cambridge University Press (2020).

Relevance. The graduate quantum-mechanics text this paper recommends for Appendix B’s prerequisites: the postulates stated cleanly, the measurement formalism developed without interpretive commitment, and — crucially for the appendix’s Step 1 — density matrices, the reduced state, and the partial trace treated as physics rather than as bookkeeping. A reader who can follow its chapter on the interaction picture and its treatment of the Berry phase has everything Appendix B assumes. The Berry-phase material is also the natural entry point to the holonomy language of Appendix A, since the geometric phase is the one holonomy most physicists meet before they meet the word. First cited in §60.

A. Zee. *Quantum Field Theory in a Nutshell*, 2nd ed., Princeton University Press (2010).

Relevance. Quantum field theory taught by physical argument rather than by axiomatics, and the text recommended for a reader who wants the ideas of Appendix C before the technology: why the path integral organizes the subject, what an effective field theory is, where the renormalization group comes from, and why anomalies exist at all. Its treatment of gauge theories and of the anomaly is the level of detail Appendix C’s Step 1 targets, and its chapters on condensed-matter analogies are useful preparation

for the semigroup reading of the flow — Kadanoff blocking appears there in its original setting, where the loss of information is obvious rather than formal. First cited in §60.

H. Georgi. *Lie Algebras in Particle Physics*, 2nd ed., Perseus (1999).

Relevance. The group theory a reader of this paper actually needs, taught as a working tool: representations, roots and weights, tensor methods, and the branching rules that decide how a large group's representations decompose when it is broken to a subgroup. Appendix D's parameter-counting theorem and Appendix C's discussion of $SU(5)$ content both assume this material, and the anomaly-coefficient arithmetic of GG-A3-B16 is unreadable without it. Georgi is recommended over the mathematicians' texts because it keeps the physics question — what does this representation contain, and what does it become — in front of the formalism throughout. First cited in §60.

S. Dodelson and F. Schmidt. *Modern Cosmology*, 2nd ed., Academic Press (2020).

Relevance. The cosmology text that treats the observational chain in the most practical detail: what a CMB experiment actually measures, how the likelihood is built, where the degeneracies lie, and how a parameter constraint is extracted. Appendix E cites it where the question is not what the theory predicts but how the comparison is made — the question Problem 7's inventory discussion and the objections about covariances turn on. A reader who wants to check for himself whether $\Omega_m = 1/\pi$ is a fair comparison against a marginalized posterior should start here. First cited in §60.

M. Nakahara. *Geometry, Topology and Physics*, 2nd ed., IOP Publishing (2003).

Relevance. The bridge text between physics and the geometry this paper is written in: fiber bundles, connections, curvature, characteristic classes, homotopy and homology, index theorems, and anomalies, all developed for physicists and all used in Appendix A. It is the single most useful reference for the technical content of the central sentence, because it makes explicit what a holonomy group *is*, why $\text{Hom}(\pi_1(M), G)/G$ is the right moduli space for flat connections, and why that space is a circle for $M = S^1$ and a point for $M = I$. A reader who works through its bundle chapters will find that this paper's anatomy claim is not exotic mathematics but the first consequence of the definitions. First cited in §60.

C. W. Misner, K. S. Thorne, and J. A. Wheeler. *Gravitation*, W. H. Freeman (1973).

Relevance. *Gravitation*: the encyclopaedic text whose geometric pedagogy — tell the reader what the object is before writing its components — this paper's exposition tries to imitate. It is recommended for Appendix A's parallel-transport material, where its pictures of a vector carried around a closed circuit on a sphere are still the clearest illustration in print of the fact that holonomy is a property of a loop and of nothing else. Its discussion of the difference between a coordinate artifact and a geometric invariant is the background a reader needs before the interval-versus-circle distinction can carry weight. First cited in §60.

T. T. Wu and C. N. Yang. *Concept of nonintegrable phase factors and global formulation of gauge fields*, Phys. Rev. D **12** (1975) 3845.

Relevance. The paper that identified the physically meaningful content of a gauge field as the non-integrable phase factor — the holonomy — rather than the potential or the field strength, and gave the global formulation in bundle language that makes the Aharonov–Bohm effect and the Dirac monopole two aspects of one statement. It is the historical hinge between gauge theory as written by physicists and gauge theory as understood by geometers, and it is therefore the most directly relevant external paper to this one's central sentence. Appendix A's Step 1 follows its dictionary — bundle, connection, holonomy on the mathematical side; gauge field, potential, phase factor on the physical side — and Problem 3's readability theorem is that dictionary applied to the question of what a measurement of a gauge theory can return. First cited in §60.

M. A. Nielsen and I. L. Chuang. *Quantum Computation and Quantum Information*, Cambridge University Press (2000).

Relevance. The standard reference for quantum information, cited here for the parts Appendix B builds on: completely positive trace-preserving maps, the Kraus representation, the operator-sum decomposition, and the entropies. The technical claim that a channel composes forward but does not in general invert is stated there in its cleanest form, and that claim is precisely what the interval side of the anatomy asserts about the physical projection. A reader who wants to test whether this paper’s use of “semigroup” is metaphorical or literal should check it against the composition law for channels given here; the answer is that it is literal. First cited in §60.

H.-P. Breuer and F. Petruccione. *The Theory of Open Quantum Systems*, Oxford University Press (2002).

Relevance. The reference text on open quantum systems, and the source for the Born–Markov derivation, the Lindblad generator, and the decoherence models that Appendix B works through in detail. Its treatment of the environment correlation functions — and of why their Fourier transforms must be positive for the dynamics to be a legitimate channel — is the technical basis for the appendix’s claim that irreversibility requires a continuous spectrum, and hence that a compact fiber cannot supply it. That single point carries a large share of the anatomy’s weight in Problems 1, 13, and 14, so a reader who doubts it should check it here first. First cited in §60.

M. E. Peskin and D. V. Schroeder. *An Introduction to Quantum Field Theory*, Addison-Wesley (1995).

Relevance. The field-theory text most readers of this paper will have been trained on, cited for the computations Appendix C’s Step 1 reproduces in outline: the beta function with its two competing contributions, the Callan–Symanzik equation, the chiral anomaly, and the renormalization of gauge theories. It is recommended for the calculational spine; the conceptual framing is better found in [Zee \(2010\)](#) and the axiomatic grounding in [Weinberg \(1995\)](#). Appendix C’s discussion of why anomaly coefficients are integers that cannot run is written against its presentation of the triangle diagram. First cited in §60.

S. Weinberg. *The Quantum Theory of Fields, Vol. I: Foundations*, Cambridge University Press (1995).

Relevance. Weinberg’s first volume: quantum field theory derived from Lorentz invariance, unitarity, and cluster decomposition rather than assumed as a formalism. It is recommended for readers who want to know which features of the standard framework are forced and which are conventional — the question this paper asks of every structure it inherits. Appendix C cites it for the derivation of the particle content from representation theory, and Problem 3’s account of gauge invariance as a redundancy rather than a symmetry is closest in spirit to Weinberg’s own presentation, in which the gauge field appears as the price of a massless helicity-one field rather than as a postulate. First cited in §60.

M. Srednicki. *Quantum Field Theory*, Cambridge University Press (2007).

Relevance. A field-theory text organized so that a reader can take the pieces in the order the argument needs them, which makes it the most convenient reference for the specific results Appendices C and H quote: the functional methods, the background-field treatment of the beta function, and the operator analysis behind the dimension-six proton-decay operators. It is recommended alongside [Peskin and Schroeder \(1995\)](#) rather than instead of it — the two are complementary in emphasis, and a student working through Appendix H will want both. First cited in §60.

M. Born. *Zur Quantenmechanik der Stoßvorgänge*, Z. Phys. **37** (1926) 863.

Relevance. The paper in which the probability interpretation of the wave function appears — famously in a footnote added in proof, the modulus squared corrected from the modulus. A century later the rule remains the one element of the quantum formalism that has never been derived from the others within the

standard framework: unitary evolution is a theorem of the postulates, the measure attached to outcomes is not. That is the whole of Problem 1’s difficulty, and it is why this paper’s status claim is carefully limited: the Born rule is closed at the relaxation level, with the field-grade representation step named as the single analytic residue rather than waved past. Everything the framework says about measurement is downstream of what Born wrote in that footnote. First cited in §3.1.

J. von Neumann. *Mathematische Grundlagen der Quantenmechanik*, Springer, Berlin (1932).

Relevance. The book that gave quantum mechanics its Hilbert-space formulation and separated its dynamics into two processes: the unitary evolution that holds when nobody looks, and the projection that occurs when somebody does. Naming the second process is what created the measurement problem in its modern form, because nothing in the formalism says when it applies. The book’s celebrated no-hidden-variables theorem, later shown by Bell to rest on an assumption stronger than necessary, is a cautionary example this paper cites for its own sake: an impossibility proof is only as strong as the class of theories it quantifies over, which is why §22 insists that every conditional result name its conditions. Problem 1 reads von Neumann’s two processes as the two fibers’ two behaviors rather than as two laws. First cited in §3.1.

A. Einstein, B. Podolsky, and N. Rosen. *Can quantum-mechanical description of physical reality be considered complete?*, Phys. Rev. **47** (1935) 777.

Relevance. The argument that quantum mechanics, if it is local, must be incomplete — from the perfect correlations of an entangled pair, together with a locality assumption, to the conclusion that the theory omits elements of reality. Its logic is often reported backwards; what EPR argued was a conditional, and Bell’s later achievement was to make the antecedent testable. This paper cites it as the origin of the dispute §58 calls the oldest in physics, and as the point at which a metaphysical preference became a physical claim with consequences. The framework’s own position on that dispute — deterministic in the bulk, probabilistic on the boundary, with 4D non-locality conceded openly — is a way of accepting the EPR conditional and denying its locality premise where the premise is cheapest to deny. First cited in §3.1.

J. S. Bell. *On the Einstein Podolsky Rosen paradox*, Physics **1** (1964) 195.

Relevance. The inequality that converted the EPR dispute into an experiment: any theory in which outcomes are determined by local hidden variables must satisfy a bound that quantum mechanics violates. It is the most important single result in the foundations of quantum mechanics, and its subsequent experimental confirmation is what forces any realist framework to be explicit about where its non-locality lives. This paper’s answer is geometric and stated without hedging: the correlations are local in the six-dimensional bulk and non-local only in their four-dimensional shadow, with the circle’s winding label as the carrier. Problem 1 treats this as a cost openly paid rather than as a difficulty finessed, and Part X returns to it whenever an objection asks what the framework gives up. First cited in §3.1.

H. Everett III. *“Relative state” formulation of quantum mechanics*, Rev. Mod. Phys. **29** (1957) 454.

Relevance. The relative-state formulation: keep the unitary evolution, drop the collapse, and read the appearance of definite outcomes as a fact about branches rather than about the world. It is cited in Problem 1 as one of the three standard responses to the measurement problem — alongside dynamical collapse (Ghirardi et al., 1986) and the decoherence program (Zurek, 2003) — and as the one that pays for its economy of postulates with an ontological extravagance, together with a well-known difficulty in recovering the measure. This paper’s route is a different trade: the outcomes are single because the projection is single-valued, and the measure is what the relaxation supplies. Whether that trade is better is a judgment the paper states rather than assumes. First cited in §3.1. First cited in §3.

G. C. Ghirardi, A. Rimini, and T. Weber. *Unified dynamics for microscopic and macroscopic systems*, Phys. Rev. D **34** (1986) 470.

Relevance. Dynamical collapse: modify the Schrödinger equation itself with a stochastic localization term, tuned so that microscopic systems evolve essentially unitarily while macroscopic superpositions collapse fast. It is the honest rival to every interpretive move, because it makes the measurement problem into a question about a rate that experiments can bound, and successive interferometry results have been closing the parameter space ever since. This paper cites it in Problem 1 both as the second standard response and as a methodological model: a proposal that buys definiteness at the price of new parameters and, in exchange, becomes falsifiable. The framework's own claim is that the definiteness comes from the interval's structure at no parametric cost, which is a stronger claim and correspondingly more exposed. First cited in §3.1.

W. H. Zurek. *Decoherence, einselection, and the quantum origins of the classical*, Rev. Mod. Phys. **75** (2003) 715.

Relevance. The review that assembled decoherence and einselection into a complete account of the emergence of classicality: the environment monitors the system, the pointer basis is the one that survives the monitoring, and interference terms decay at rates that can be computed and measured. Everything in it is used here and none of it is disputed. What Problem 1 observes is the well-known residue — decoherence explains why the off-diagonal terms vanish and which basis is selected, but not why one diagonal entry is realized rather than another, and not why the weights are what they are. On this paper's anatomy the part decoherence explains is the interval's part, which is why the program works so well and stops exactly where it does. First cited in §3.1.

E. Fermi. *Versuch einer Theorie der β -Strahlen*, Z. Phys. **88** (1934) 161.

Relevance. The first quantum field theory of a force other than electromagnetism: beta decay as a four-fermion contact interaction, with a coupling constant G_F carrying dimensions of inverse mass squared. It worked, and its failure mode taught the field its most valuable lesson — a dimensionful coupling means the theory is an effective description with a ceiling, and the ceiling turned out to be the W boson. Problem 2 cites it as the origin of the puzzle it addresses: the interactions look unlike partly because they are described at different depths of the same effective tower, and the framework's claim is that the depth is a position on the interval and the label at that depth is a phase on the circle. First cited in §3.2. First cited in §3.

C. N. Yang and R. L. Mills. *Conservation of isotopic spin and isotopic gauge invariance*, Phys. Rev. **96** (1954) 191.

Relevance. The generalization of the gauge principle to a non-abelian group, written for isotopic spin and rejected at the time for predicting massless charged vector bosons that nobody had seen. It is now the mathematical spine of three of the four interactions, and its history is the standard example of a structure being right before its physical realization was understood. Problem 2 uses it as the point at which force ceased to be a list and became a representation-theoretic question, and Problem 3 uses it as the first place where a local symmetry was recognized as a redundancy imposed on the description rather than an observable property — which is exactly the reading the anatomy makes geometric. First cited in §3.2.

S. Weinberg. *A model of leptons*, Phys. Rev. Lett. **19** (1967) 1264.

Relevance. The three-page paper that unified the electromagnetic and weak interactions for leptons, with the Higgs mechanism supplying the masses and the weak mixing angle as the one new parameter. It was almost uncited for four years, until renormalizability was established, and then became the most cited paper in particle physics — a history this paper notes in Problem 2 because it illustrates how much of the field's confidence in a structure depends on being able to compute with it. The mixing angle is where this paper's interest lies: the standard framework measures $\sin^2 \theta_W$, and the cohort computes it as

$25/108 = 0.23148$ from the ledger, a comparison that is either a coincidence or the point. First cited in §3.2.

D. J. Gross and F. Wilczek. *Ultraviolet behavior of non-abelian gauge theories*, Phys. Rev. Lett. **30** (1973) 1343.

Relevance. Asymptotic freedom: the discovery that a non-abelian gauge theory’s coupling weakens at short distances, which made QCD possible and explained why quarks behave as free particles inside a nucleon while being permanently bound. It is cited in Problem 2 as the resolution of the apparent contradiction between the parton picture and confinement, and in Problem 12 as the reason the confinement problem is hard: the strong coupling regime where confinement lives is the regime perturbation theory cannot reach. The two competing contributions to the beta function — fermion screening against gluon antiscreening — are worked in Appendix C’s Step 1, because the sign of that competition is what the whole picture turns on. First cited in §3.2.

H. D. Politzer. *Reliable perturbative results for strong interactions?*, Phys. Rev. Lett. **30** (1973) 1346.

Relevance. The independent discovery of asymptotic freedom, published back to back with Gross and Wilczek (1973) and sharing the Nobel Prize with it. Cited alongside its companion throughout Problem 2 and Problem 12, and noted here for the same methodological reason this paper keeps returning to: two independent routes to one result is the strongest evidence a field ever gets, which is why the cohort’s genuine two-route derivation — $N_g = 3$, from the constitutional chain and from Arisaka’s capacity bound, which share no step — is presented as load-bearing, while K is presented as what it is: one derivation, spent four ways. First cited in §3.2.

H. Georgi and S. L. Glashow. *Unity of all elementary-particle forces*, Phys. Rev. Lett. **32** (1974) 438.

Relevance. Minimal $SU(5)$: the proposal that the three Standard Model gauge groups are the low-energy remnants of one simple group, which explains charge quantization, predicts the weak mixing angle, and requires proton decay. The prediction was its virtue and its undoing — the minimal version’s proton lifetime has been excluded by Takenaka et al. (2020) and its descendants — but the idea that the gauge structure is the shadow of something simpler has never been abandoned. This paper cites it as the program it belongs to and departs from: the cohort’s unification is geometric rather than group-theoretic, the proton is protected by a double guard rather than by a single mass scale, and the resulting lifetime is a consequence rather than a fitted upper bound. First cited in §3.2.

H. Weyl. *Gravitation und Elektrizität*, Sitzungsber. Preuss. Akad. Wiss. (1918) 465.

Relevance. The first attempt to unify electromagnetism with gravity by making the local scale of length a gauge freedom, and the first geometric unification to be killed by an experiment it had not anticipated: Einstein’s objection that a locally gauged length makes a clock’s rate depend on its path, so that atoms with different histories would show different spectra. They do not. It is cited here, in §24, against this paper’s own interest: Weyl gauged the scale direction, this framework’s fifth dimension *is* the scale direction, and the whole difference between the two is that here it carries no gauge-invariant content. The reader is entitled to weigh how thin a margin that is. First cited in §24.

H. Weyl. *Elektron und Gravitation. I*, Z. Phys. **56** (1929) 330.

Relevance. The paper that gave the gauge principle its modern form: invariance of the Dirac field under a local change of phase requires the electromagnetic potential, and the potential’s transformation law is fixed by that requirement. Weyl had tried the same idea a decade earlier with a local change of *scale*, which failed; the survival of the name “gauge” from the failed version is a historical accident the field has never corrected. Problem 3 cites it as the origin of the question it asks — why should nature be organized around a redundancy? — and reads Weyl’s own instinct as vindicated in an unexpected way: the phase is

a coordinate on a compact fiber, and the scale is a coordinate on an open one, so both of his ideas were geometry, but only one of them was a symmetry. First cited in §3.3. First cited in §3.

F. J. Dyson. *The radiation theories of Tomonaga, Schwinger, and Feynman*, Phys. Rev. **75** (1949) 486.

Relevance. The paper that showed the Tomonaga, Schwinger, and Feynman formulations to be the same theory, and organized renormalization into a systematic procedure rather than a sequence of rescues. It is the moment renormalization became a technique physicists could trust without knowing what it meant — a state of affairs that lasted twenty-five years until [Wilson and Kogut \(1974\)](#) explained it. Problem 3 cites the pair together deliberately, because the gap between them is the paper’s point: a procedure that works long before it is understood is a signal that a structure is being used without being seen, and the framework’s claim is that the structure is the interval. First cited in §3.3.

G. ’t Hooft and M. Veltman. *Regularization and renormalization of gauge fields*, Nucl. Phys. B **44** (1972) 189.

Relevance. Dimensional regularization and the renormalization of gauge theories — the technical achievement that made the electroweak model calculable and therefore believable, and the reason [Weinberg \(1967\)](#) moved from obscurity to ubiquity. It is cited in Problem 3 as the completion of the program [Dyson \(1949\)](#) began, and as a specific illustration of the point Appendix C’s Step 1 develops: the regulator has to respect the gauge structure or the anomaly cancellation is destroyed by the arithmetic of the calculation rather than by physics. That the consistent regulator exists, and that anomaly coefficients come out as integers regardless of how the calculation is organized, is the fact Problem 3 reads as circle-side bookkeeping. First cited in §3.3.

S. Elitzur. *Impossibility of spontaneously breaking local symmetries*, Phys. Rev. D **12** (1975) 3978.

Relevance. The theorem that a local gauge symmetry cannot be spontaneously broken: gauge-non-invariant order parameters have vanishing expectation values, and what the Higgs mechanism does is not break a symmetry but remove a redundancy in a particular gauge. The result is standard, uncontroversial, and routinely ignored in the language physicists actually use, which is why Problem 3 gives it a section of its own. On this paper’s reading Elitzur’s theorem is a corollary of a more basic statement — what a measurement can return is a holonomy, and a holonomy is gauge invariant by construction — so the impossibility is not a technical obstruction but a statement about what is written on the circle and what is merely a chart. First cited in §3.3.

S. Navas et al. (Particle Data Group). *Review of Particle Physics*, Phys. Rev. D **110** (2024) 030001.

Relevance. The Review of Particle Physics: the reference against which every particle-sector number in this paper is checked, and the source of the parameter inventory Problem 4 is about. It is cited for the masses, the mixing matrices, the coupling constants at their quoted scales and schemes, and the experimental limits that make the falsifier table’s kill conditions concrete. The Review also supplies a discipline this paper tries to keep: every quoted value carries a scheme, a scale, and an uncertainty, and a comparison that drops any of the three is not a comparison. Appendix D’s Step 1 spends several pages on exactly this point before any closed form is compared to anything. First cited in §3.4.

R. N. Cahn. *The eighteen arbitrary parameters of the standard model in your everyday life*, Rev. Mod. Phys. **68** (1996) 951.

Relevance. The essay that made the parameter problem vivid by asking what the Standard Model’s arbitrary numbers actually do — which of them set the size of an atom, the lifetime of a star, the stability of a nucleus — and showing how narrowly the world depends on values the theory cannot compute. It is cited in Problem 4 as the clearest statement of why the count matters: the numbers are not bookkeeping, they are the settings on which everything else rests, and a framework that computes them is making a

claim of a different kind from one that fits them. The count itself is convention-dependent, which is why Appendix D’s Step 1 works through the $36 - (27 - 1) = 10$ theorem and the full sector-by-sector tally before the codebook comparison is attempted. First cited in §3.4.

G. Lemaître. *The beginning of the world from the point of view of quantum theory*, Nature **127** (1931) 706.

Relevance. The primeval-atom proposal: the universe began in a single quantum of enormous energy whose disintegration produced everything else — the first statement that the cosmos has a beginning that physics might describe rather than assume. Problem 5 cites it as the origin of its question and as an early instance of the pattern the paper keeps noticing: a structural proposal, made before any instrument could address it, that turned out to be answerable. Lemaitre’s own caution — that the beginning would need a quantum treatment — is the position the framework still occupies, with the entrance corridor supplied as a work order rather than as a completed derivation. First cited in §4.1.

S. W. Hawking and R. Penrose. *The singularities of gravitational collapse and cosmology*, Proc. R. Soc. A **314** (1970) 529.

Relevance. The singularity theorems in their most general form: given reasonable energy conditions and a trapped surface or its cosmological analog, geodesic incompleteness is unavoidable, and no amount of symmetry-breaking cleverness in the initial data will remove it. The theorems are cited in Problem 5 as the reason the beginning is a problem of principle rather than of modeling — classical general relativity predicts its own failure — and as the standing constraint on any proposal about what preceded the descent. This paper’s position is that the incompleteness is real and that the interval’s endpoint is where it lives, which converts the singularity from a breakdown into a boundary with a work order attached. First cited in §4.1.

A. Borde, A. H. Guth, and A. Vilenkin. *Inflationary spacetimes are incomplete in past directions*, Phys. Rev. Lett. **90** (2003) 151301.

Relevance. The theorem that inflationary spacetimes are past-incomplete: an expanding region, however long it inflates, cannot be extended indefinitely into the past along every geodesic. It removed the most popular escape from the beginning — eternal inflation as a way of never having to start — and is cited in Problem 5 for exactly that reason. The result matters to the anatomy because it says something about the shape of the scale direction: a coordinate along which the physical evolution runs one way and cannot be continued backwards indefinitely is an interval with an endpoint, not a line. What the framework adds is that the endpoint is the arena’s, not an artifact of the matter content. First cited in §4.1.

R. Penrose. *Singularities and time-asymmetry*, in *General Relativity: An Einstein Centenary Survey*, Cambridge (1979).

Relevance. The Weyl curvature hypothesis: the universe began in a state of extraordinarily low gravitational entropy, and the improbability of that state — Penrose’s celebrated estimate is one part in $10^{10^{123}}$ — is the real content of the second law. It is the sharpest available statement of why the arrow of time is a cosmological problem rather than a statistical one, and it is why Problem 13 cannot be answered by coarse-graining arguments alone. This paper’s response is structural rather than statistical: if the physical composition along the descent has no inverse, the arrow does not need a past hypothesis to explain it, and Appendix I’s Step 3 shows explicitly why Loschmidt’s and Zermelo’s objections both fail against a semigroup. First cited in §4.1.

P. A. M. Dirac. *The cosmological constants*, Nature **139** (1937) 323.

Relevance. The large-numbers hypothesis: Dirac’s observation that several dimensionless ratios built from the fundamental constants come out near 10^{40} or its powers, and his conjecture that the coincidences reflect a law rather than an accident — with the consequence, since excluded, that G_N varies with cosmic

time. It is cited in Problem 6 as the ancestor of every hierarchy argument and as an object lesson in both directions: the instinct that unexplained large ratios demand explanation was right, and the specific mechanism proposed for it was wrong and was killed by measurement. The cohort's own large-number claims are held to the standard that episode set, which is why $M_{\text{lock}} = \frac{1}{2} M_{\text{Pl}} e^{-K}$ is stated with a resonance to look for rather than as an interpretive flourish. First cited in §4.2.

- L. Susskind.** *Dynamics of spontaneous symmetry breaking in the Weinberg–Salam theory*, Phys. Rev. D **20** (1979) 2619.

Relevance. The paper that stated the gauge hierarchy problem in the form the field has worried about ever since: the Higgs mass receives quadratically divergent corrections, so keeping the electroweak scale far below the Planck scale requires a cancellation to many decimal places unless some structure protects it. Technicolor was the proposed structure; supersymmetry became the more popular one; neither has been found. Problem 6 cites it as the statement of the debt and then declines both standard payments: on this paper's reading the loop's reach is bounded by the same warp factor e^{-K} that sets the lock scale, so $\delta m_H^2/m_H^2$ is of order unity and no cancellation is invoked — at the price of a completion that must exist at 3.849 TeV. First cited in §4.2.

- G. 't Hooft.** *Naturalness, chiral symmetry, and spontaneous chiral symmetry breaking*, in *Recent Developments in Gauge Theories*, NATO ASI Series B **59** (1980) 135.

Relevance. The naturalness criterion: a small dimensionless parameter is natural if setting it to zero enhances the symmetry of the theory, because then the smallness is protected against radiative corrections by that symmetry. It is the most influential single idea in model-building since the Standard Model was completed, and its predictions for the LHC did not come true, which is why Problem 6 treats it with care rather than dismissal. This paper's position is that the criterion is correct and that its symmetry clause is too narrow: protection can also come from topology, with no symmetry anywhere (Hopkins and Singer, 2005), and the circle side of the anatomy is exactly where that second kind of protection lives. First cited in §4.2. First cited in §4.

- F. Zwicky.** *Die Rotverschiebung von extragalaktischen Nebeln*, Helv. Phys. Acta **6** (1933) 110.

Relevance. The Coma cluster virial analysis: the galaxies are moving too fast for the luminous mass to hold them, so most of the mass is dark. The observation was ignored for four decades, which makes it the field's standard example of a correct result arriving before the community was ready to use it. It is cited in Problem 7 as the beginning of the dark-matter question and as a reminder that the evidence for the dark sector is dynamical and gravitational — the sector's existence is far better established than any proposal for what it is made of, which is why the framework's Kaxion is stated as a line to look for rather than as a claim already banked. First cited in §4.3. First cited in §4.

- V. C. Rubin and W. K. Ford.** *Rotation of the Andromeda nebula from a spectroscopic survey of emission regions*, Astrophys. J. **159** (1970) 379.

Relevance. The spectroscopic rotation curve of the Andromeda nebula: emission-region velocities that stay flat far outside the luminous disc instead of falling as Kepler requires. It is one galaxy, studied carefully, and the survey of many galaxies that made the result decisive came later in the decade — a distinction this paper keeps because its own reproducibility standard demands it. Problem 7 cites it as the observation that made dark matter unavoidable rather than merely available, and as the second half of the pairing with Zwicky (1933): cluster dynamics and galactic dynamics, two independent scales, one conclusion. First cited in §4.3.

- S. Weinberg.** *A new light boson?*, Phys. Rev. Lett. **40** (1978) 223.

Relevance. One of the two papers that recognized the consequence of the Peccei–Quinn proposal: a spontaneously broken global symmetry leaves a light pseudoscalar behind, and the strong CP solution therefore predicts a new particle whose mass and couplings are fixed by the symmetry-breaking scale. The axion has been searched for ever since, and the search is now the most sensitive dark-matter program running in the microwave band. Problem 7 cites this and Wilczek (1978) for the mechanism the cohort’s Kaxion inherits, with the one modification that matters: the breaking scale is not chosen but computed as $f_K = f_{\text{bulk}}/\Xi_{\text{cap}}$, which turns a family of candidates into a line. First cited in §4.3.

F. Wilczek. *Problem of strong P and T invariance in the presence of instantons*, Phys. Rev. Lett. **40** (1978) 279.

Relevance. The independent identification of the axion, published alongside Weinberg (1978) and cited together with it throughout Problem 7. The paper’s framing — that the strong P and T problem is solved by a dynamical field rather than by a tuned angle — is the template the cohort follows, and it is also the historical origin of the naming convention the framework’s own particle inherits. What the pair leaves open is the decay constant, and that is exactly the gap the Kaxion’s $\Xi_{\text{cap}} = K + N + L = 43$ closes, at the cost of a benchmark loading that the honest ledger lists as an open integer with a discrete search window rather than as a derived value. First cited in §4.3.

C. W. Misner. *The isotropy of the universe*, Astrophys. J. **151** (1968) 431.

Relevance. The paper that made the horizon problem quantitative: the microwave background is isotropic to a part in 10^5 across regions that, in a decelerating universe, were never in causal contact, and Misner’s mixmaster proposal was the first serious attempt to explain the agreement dynamically rather than assume it. The attempt failed and the problem survived, to be answered a decade later by inflation. Problem 8 cites it as the statement of the puzzle in its cleanest pre-inflationary form, because the puzzle is what the framework’s corridor has to solve: distant strangers agree because they were compiled from the same bulk data along a descent that had one traverse, not because a mixing dynamics equalized them. First cited in §4.4.

T. D. Lee and C. N. Yang. *Question of parity conservation in weak interactions*, Phys. Rev. **104** (1956) 254.

Relevance. The paper that noticed nobody had ever tested parity in the weak interaction, surveyed the existing data to confirm the gap, and proposed the experiments that would close it. It is the field’s best example of a symmetry assumed for so long that its assumption became invisible, and Problem 9 opens with it for that reason: the mirrors were taken to be exact because no one had looked. On this paper’s reading the episode is also a lesson in what kind of thing a discrete symmetry is — an orientation the geometry either admits or does not, rather than a principle the world is obliged to respect — and the anatomy’s business is to say which orientations exist and which fiber carries each. First cited in §5.1. First cited in §5.

C. S. Wu, E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson. *Experimental test of parity conservation in beta decay*, Phys. Rev. **105** (1957) 1413.

Relevance. The cobalt-60 experiment: polarized nuclei emitting beta electrons preferentially against their spin direction, in maximal violation of parity. The result arrived within months of the proposal and overturned an assumption that had organized physics for decades. Problem 9 cites it as the first of the three mirrors to break, and Appendix G’s Step 1 works through the bilinear transformation table that makes the violation precise. What the anatomy adds is a reason the breaking is maximal rather than partial: the chirality that parity exchanges is a label on the compact fiber, and a projection that keeps one chirality and discards the other is what an interval does to a circle-side pair. First cited in §5.1.

J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay. *Evidence for the 2π decay of the K_2^0 meson*, Phys. Rev. Lett. **13** (1964) 138.

Relevance. The discovery of CP violation in neutral kaon decay: a two-pion final state at the level of 2×10^{-3} , where CP conservation forbids it entirely. The result was unwanted, small, and correct, and it made the matter–antimatter asymmetry of the universe a question physics could address rather than a brute fact. Problem 9 cites it as the second mirror and Problems 10–11 cite it as the enabling condition for the second Sakharov requirement. Its size is also part of the difficulty: CP violation exists, it is measured, and [Gavela et al. \(1994\)](#) showed that the amount available in the quark sector is nowhere near enough. First cited in §5.1. First cited in §5.

G. Lüders. *On the equivalence of invariance under time reversal and under particle-antiparticle conjugation for relativistic field theories*, Kgl. Danske Vid. Selskab, Mat.-fys. Medd. **28**, no. 5 (1954) 1.

Relevance. The CPT theorem: any local, Lorentz-invariant quantum field theory with a Hermitian Hamiltonian is invariant under the combined operation, whatever happens to C, P, and T individually. It is the most robust discrete statement in physics — the equality of particle and antiparticle masses and lifetimes has been checked to parts in 10^{18} — and it is the fact Problem 9 has to explain rather than assume. The anatomy’s answer is that the three individual operations are orientation reversals a bundle may or may not admit, while their product is the total orientation of the whole six-dimensional structure, which the geometry cannot reverse without ceasing to be itself. Appendix G’s Step 1 gives the standard proof in outline; Step 3 gives the geometric restatement. First cited in §5.1.

G. ’t Hooft. *Symmetry breaking through Bell–Jackiw anomalies*, Phys. Rev. Lett. **37** (1976) 8.

Relevance. The paper that showed the QCD vacuum has a topological structure — the θ angle — and that baryon and lepton number are violated by the electroweak anomaly, both consequences of instanton configurations that perturbation theory cannot see. It creates two of this paper’s problems at once. The θ angle creates the strong CP problem of Problem 9, because nothing in QCD explains why the measured value is smaller than 10^{-10} ([Abel et al., 2020](#)). The anomalous $B + L$ violation supplies the first Sakharov condition of Problems 10–11 by way of sphalerons ([Kuzmin et al., 1985](#)). Both are circle-side statements in the anatomy: winding numbers, integer-valued, immune to the running that the interval governs. First cited in §5.1.

C. Abel et al. *Measurement of the permanent electric dipole moment of the neutron*, Phys. Rev. Lett. **124** (2020) 081803.

Relevance. The current best limit on the neutron’s permanent electric dipole moment, $|d_n| < 1.8 \times 10^{-26} e \text{ cm}$ at 90% confidence — the measurement that bounds the QCD vacuum angle below 10^{-10} and thereby makes the strong CP problem quantitative. It stands here as the model of what this paper means by an instrument closing a question: a structural puzzle about a parameter that theory permits to be of order one, converted by an experiment into a ten-order-of-magnitude gap that has to be explained by something. The cohort’s response is Problem 9’s color-triangle account, and the same instrument is one of the falsifier table’s live kills. First cited in §2.

P. A. M. Dirac. *The quantum theory of the electron*, Proc. R. Soc. A **117** (1928) 610.

Relevance. The relativistic wave equation for the electron, which produced spin and the correct magnetic moment as consequences rather than inputs, and left negative-energy solutions that Dirac initially and incorrectly identified with protons. The correction — a new particle of the same mass and opposite charge — came in 1931 ([Dirac, 1931](#)), and the particle was found in 1933 ([Anderson, 1933](#)). Problems 10–11 cite the sequence because it is the cleanest instance in the record of the pattern this paper is claiming for itself: a structure forced by consistency, resisted because its consequence seemed absurd, and confirmed by measurement within five years. First cited in §5.2.

C. D. Anderson. *The positive electron*, Phys. Rev. **43** (1933) 491.

Relevance. The cloud-chamber photograph that established the positron: a track of electron mass curving the wrong way in a magnetic field. Antimatter stopped being an interpretive difficulty and became a particle. Problems 10–11 cite it as the completion of the Dirac sequence and as the beginning of the asymmetry question in its modern form — if the laws produce matter and antimatter on equal terms, and the early universe was hot enough to make both, the survival of one and not the other is something that has to have happened rather than something that can be assumed. First cited in §5.2.

V. A. Kuzmin, V. A. Rubakov, and M. E. Shaposhnikov. *On anomalous electroweak baryon-number non-conservation in the early universe*, Phys. Lett. B **155** (1985) 36.

Relevance. Electroweak sphalerons: the demonstration that anomalous baryon-number violation, exponentially suppressed at zero temperature, becomes rapid at temperatures above the electroweak scale, so that $B + L$ is efficiently erased in the early universe while $B - L$ survives. It is the fact that makes leptogenesis work — a lepton asymmetry generated at high scale is partially converted to baryon number by the same process — and therefore the load-bearing input to Problems 10–11. Appendix G’s Step 1 works through the barrier energetics; the anatomy reads the sphaleron as a circle-side transition between vacua labeled by winding number, executed because the interval’s descent supplied the thermal energy to cross the barrier. First cited in §5.2.

M. Gell-Mann. *A schematic model of baryons and mesons*, Phys. Lett. **8** (1964) 214.

Relevance. The quark model: hadrons as composites of three fractionally charged constituents, proposed as a classification scheme with an explicit agnosticism about whether the constituents were real. They were, and their non-appearance as free particles became the confinement problem of Problem 12. This paper cites the proposal for the shape of the puzzle it created: a theory whose fundamental fields are never observed in isolation, which forces a distinction between what the theory contains and what an experiment can return — exactly the distinction the anatomy draws between the description and the holonomy that is readable from it. First cited in §5.3.

O. W. Greenberg. *Spin and unitary-spin independence in a paraquark model of baryons and mesons*, Phys. Rev. Lett. **13** (1964) 598.

Relevance. The observation that the quark model’s baryon wave functions were symmetric where Fermi statistics required antisymmetry, and that a hidden threefold degree of freedom would fix it — parastatistics then, color now. It is the origin of the number three in the strong interaction, and Problem 12’s why-three-colors section is written against it. The framework’s claim is that the same integer arrives twice by routes with no shared step: as the $\mathbb{Z}_3$ center of the winding structure and as the count that Arisaka (2026, P2-N3)’s open-system bound returns, which is the kind of overdetermination this paper treats as evidence rather than as decoration. First cited in §5.3.

A. Jaffe and E. Witten. *Quantum Yang–Mills theory*, in *The Millennium Prize Problems*, Clay Mathematics Institute (2006).

Relevance. The Clay Millennium Prize description of the Yang–Mills problem, which is worth stating precisely because it is routinely misquoted: the prize is for constructing a rigorous quantum Yang–Mills theory on $\mathbb{R}^4$ with a positive mass gap, not for proving confinement. Problem 12 cites it for that precision and takes the standard seriously: the framework’s account of confinement is graded *reread*, not *solved*, because a geometric reading of why the registration rule holds is not a proof of the mass gap and the paper says so in both the master table and the honest ledger. First cited in §5.3.

A. Takenaka et al. (Super-Kamiokande). *Search for proton decay via $p \rightarrow e^+ \pi^0$ and $p \rightarrow \mu^+ \pi^0$ with an enlarged fiducial volume*, Phys. Rev. D **102** (2020) 112011.

- Relevance.** The Super-Kamiokande proton-decay search with the enlarged fiducial volume, setting partial lifetime limits beyond 10^{34} years for the $e^+\pi^0$ and $\mu^+\pi^0$ channels — the measurement that killed minimal $SU(5)$ (Georgi and Glashow, 1974) and constrains every grand unified successor. Problem 12 cites it as the standing bound the framework’s double guard must clear, and the falsifier table lists proton decay as a live kill: the cohort’s two integrality conditions predict a lifetime, and the next generation of detectors will test it. This is one of the entries that makes the framework killable on a decade timescale rather than in principle. First cited in §5.3.
- L. Boltzmann.** *Über die Beziehung zwischen dem zweiten Hauptsatze der mechanischen Wärmetheorie und der Wahrscheinlichkeitsrechnung*, Wien. Ber. **76** (1877) 373.
- Relevance.** The paper that gave entropy its probabilistic meaning — $S = k \log W$, the logarithm of the number of microstates compatible with a macrostate — and with it the first mechanical account of the second law. It also created the difficulty Problem 13 exists to address, since the underlying mechanics is time-symmetric and the conclusion is not: Loschmidt’s reversibility objection and Zermelo’s recurrence objection are both correct as stated against the original derivation. Appendix I’s Step 1 works through the H-theorem with both objections in place, and Step 3 shows why they fail against a composition law that has no inverse — which is the anatomy’s reason for the arrow, requiring no past hypothesis to supplement it. First cited in §6.1.
- A. S. Eddington.** *The Nature of the Physical World*, Cambridge University Press (1928).
- Relevance.** The book that named the arrow of time and stated its status with a bluntness that has not been improved on: the second law holds, in Eddington’s judgment, the supreme position among the laws of nature. Problem 13 cites it for the naming and for the framing — that the one-wayness of time is not a detail of thermodynamics but the feature of the world most in need of a foundation. This paper’s answer places the one-wayness in the arena rather than in the initial conditions or the statistics, which is a stronger claim than the standard one and is graded accordingly. First cited in §6.1.
- B. S. DeWitt.** *Quantum theory of gravity. I. The canonical theory*, Phys. Rev. **160** (1967) 1113.
- Relevance.** The canonical quantization of general relativity, and the origin of the problem of time: the Hamiltonian constraint annihilates the wave function of the universe, so the fundamental equation contains no time parameter at all. Half a century of proposals — relational time, thermal time, emergent time — have not produced consensus, which is why Problem 13 treats the question as open in the standard framework rather than as awkward. The cohort’s position is that the tick is derived rather than postulated: $E = h\nu$ read as an angular velocity on the compact fiber makes the rate of a clock a geometric quantity, and Appendix I’s Step 3 carries out the derivation. First cited in §6.1.
- R. P. Feynman, R. B. Leighton, and M. Sands.** *The Feynman Lectures on Physics*, Vol. I, Addison-Wesley (1963).
- Relevance.** The Lectures, cited for one sentence and one lesson. The sentence is Feynman’s admission that physics has no knowledge of what energy is — it computes a number that does not change, and the constancy is the whole of what is known. The lesson is Problem 14’s: the three most-used quantities in physics, energy, mass, and entropy, are defined operationally and understood structurally not at all, which is a strange state of affairs for concepts so central. This paper’s answers are geometric — energy as the circle’s angular rate, mass as the cost of the interval’s position, entropy as the count of what the composition discarded — and they are offered in the register Feynman used, as an attempt to say what the quantity is rather than how to compute it. First cited in §6.2.
- J. D. Bekenstein.** *Black holes and entropy*, Phys. Rev. D **7** (1973) 2333.

Relevance. The proposal that a black hole carries entropy proportional to its horizon area, forced by the requirement that the second law survive an object falling in. It is the beginning of black-hole thermodynamics and of the holographic instinct that has organized the subject since, and its strangeness is the point Problem 16 begins from: the entropy scales with area rather than volume, so the information capacity of a region is set by its boundary. Problem 14 cites it as the third of its three quantities made geometric, and Appendix I's Step 1 derives S_{BH} from the Schwarzschild data as a worked problem so that a student can see the factor of four arrive. First cited in §6.2.

S. W. Hawking. *Particle creation by black holes*, Commun. Math. Phys. **43** (1975) 199.

Relevance. The calculation that made black-hole thermodynamics literal rather than analogical: a black hole radiates with a thermal spectrum at temperature $T_H = \hbar c^3 / 8\pi G_N M k_B$, so the horizon entropy is entropy and the surface gravity is temperature. The result is the single most important input to Problem 16, and its consequence — that the hole evaporates — is what turns an accounting curiosity into a paradox. Appendix I's Step 1 sketches the Bogoliubov derivation and Step 3 asks what the framework has to say about a formula that spends $\hbar$, G_N , and k_B in one expression: on the anatomy's reading no single fiber can produce it, which is why the horizon is where both fibers are visible at once. First cited in §6.4. First cited in §6.

S. W. Hawking. *Breakdown of predictability in gravitational collapse*, Phys. Rev. D **14** (1976) 2460.

Relevance. The paper that stated the information paradox: if a black hole forms from a pure state and evaporates completely into thermal radiation, unitarity fails, and quantum mechanics as we have it is wrong somewhere. Hawking's own conclusion — that predictability breaks down — was resisted for thirty years and eventually withdrawn, but the argument's structure has never been faulted, only answered. Problem 16 cites it as the statement of the debt and reads the resolution as a billing error rather than a new physical process: the circle keeps what the hole must return, the interval prices the return, and the two books reconcile on the schedule Page (1993) computed. First cited in §6.4.

D. N. Page. *Information in black hole radiation*, Phys. Rev. Lett. **71** (1993) 3743.

Relevance. The Page curve: if evaporation is unitary, the entanglement entropy of the radiation must rise until roughly half the hole's entropy has been emitted and then fall to zero, and the turning point is fixed by counting alone. It is the most useful single constraint in the subject because it is kinematic — any unitary account must reproduce it, whatever the mechanism — which makes it a test rather than a model. Problem 16 uses it as the reconciliation schedule of the two books and Appendix I's Step 1 shows why the curve is forced rather than derived from dynamics. The recent island computations (Penington, 2020) recover it, and this paper places that achievement intact rather than in competition. First cited in §6.4.

L. Susskind, L. Thorlacius, and J. Uglum. *The stretched horizon and black hole complementarity*, Phys. Rev. D **48** (1993) 3743.

Relevance. Black hole complementarity: the proposal that the infalling and distant descriptions are both correct and never comparable, because no single observer can check them against each other — a consistency argument rather than a mechanism. It held the field for two decades until Almheiri et al. (2013) showed that the postulates it combined were mutually inconsistent. Problem 16 cites it as the most sophisticated version of the move this paper declines: rather than declaring two descriptions incomparable, the framework says which fiber each one reads, and the two books reconcile in a single accounting instead of being kept apart. First cited in §6.4. First cited in §6.

J. M. Maldacena. *The large- N limit of superconformal field theories and supergravity*, Adv. Theor. Math. Phys. **2** (1998) 231.

Relevance. The AdS/CFT correspondence: a gravitational theory in the bulk of anti-de Sitter space is equivalent to a conformal field theory on its boundary, with the radial coordinate of the bulk identified with the renormalization scale of the boundary theory. It is the most successful bulk–boundary dictionary in physics and the closest structural relative of this framework’s own projection, which is why Part VII treats the comparison explicitly rather than in passing. The differences are stated as plainly as the debt: this bulk is six-dimensional with two fibers of different topology rather than asymptotically AdS, the boundary is our spacetime rather than a fictitious screen, and the radial–scale identification is a theorem here rather than a conjecture supported by evidence. First cited in §6.4. First cited in §6.

- A. Strominger and C. Vafa.** *Microscopic origin of the Bekenstein–Hawking entropy*, Phys. Lett. B **379** (1996) 99.

Relevance. The exact statistical-mechanical count of the microstates of an extremal black hole, reproducing the Bekenstein–Hawking area law with no adjustable factor. It is cited in §38.3 on the opposing program’s behalf: whatever one concludes about the landscape, this result stands, and it is the strongest existing evidence that horizon entropy counts something rather than measuring an observer’s ignorance. Problem 16’s two-book reading has to be consistent with it, and is. First cited in §38.3.

- A. Almheiri, D. Marolf, J. Polchinski, and J. Sully.** *Black holes: complementarity or firewalls?*, JHEP **02** (2013) 062.

Relevance. The firewall argument: black hole complementarity, the equivalence principle, and unitary evaporation cannot all hold, and something dramatic must fail at the horizon of an old black hole. It is the sharpest statement of what the information paradox actually costs, and it is why Problem 16 cannot be treated as settled by the island computations alone. This paper’s account claims no firewall, because on the two-fiber reading nothing needs to be destroyed at the horizon — the information is on the circle’s books throughout, and the interval’s descent controls only when it is returned. That is a strong claim and it is stated as one, with the grade attached. First cited in §6.4.

- G. Penington.** *Entanglement wedge reconstruction and the information paradox*, JHEP **09** (2020) 002.

Relevance. The entanglement-wedge computation that recovered the Page curve from a gravitational path integral, with the quantum extremal surface jumping at the Page time — the result that, with its companions, convinced the field that Hawking radiation is unitary after all. It is cited in Problem 16 with its achievement intact: the calculation is the strongest evidence available that the information comes out, and this framework’s account has to agree with it rather than replace it. What the paper adds is a reading of *why* the entropy turns over — two sets of books with different closure properties, reconciling — and a claim that the island’s appearance is what that reconciliation looks like in the gravitational description. First cited in §6.4.

- S. Weinberg.** *Anthropic bound on the cosmological constant*, Phys. Rev. Lett. **59** (1987) 2607.

Relevance. The anthropic bound on the cosmological constant, and the entry most often misreported in the literature. Weinberg argued that if Λ were larger than a certain value, structure would never form and no observers would exist, and he derived an *upper bound* that lies roughly two orders of magnitude above the value subsequently measured. That is a successful bound, not a successful prediction, and the distinction matters to Problem 15’s whole argument: an anthropic constraint explains why we do not observe a much larger value, and says nothing about why we observe the value we do. This paper’s alternative is to compute the number instead — the residual scale $m_\Lambda = 6.1$ meV from the lock and the reduced Planck mass — and to accept the exposure that computing it creates. First cited in §6.3.

- R. Bousso and J. Polchinski.** *Quantization of four-form fluxes and dynamical neutralization of the cosmological constant*, JHEP **06** (2000) 006.

Relevance. The mechanism that turned anthropic reasoning from a philosophical stance into a concrete construction: many four-form fluxes, each quantized, whose combinations produce an enormous discretuum of vacuum energies dense enough that some member sits near the observed value. It is the technical foundation of the landscape, and Problem 15 cites it as the strongest version of the position the paper argues against. The disagreement is structural and admits no compromise: a framework whose census permits exactly one bulk of exactly this shape has no room to accommodate a different answer, so it can be killed by a single measurement, whereas a discretuum absorbs any result. Which of those is a virtue is the question Problem 15 puts to the reader. First cited in §6.3.

L. Susskind. *The anthropic landscape of string theory*, arXiv:hep-th/0302219 (2003).

Relevance. The essay that named the anthropic landscape and argued that string theory’s enormous vacuum count, combined with eternal inflation, makes environmental selection the correct explanation for the constants rather than a failure of explanation. It is the clearest statement of the position Problem 15 is written against, and this paper takes it seriously enough to state its strength: if the constants really are environmental, then a framework that computes them is attempting something that cannot be done, and the framework will fail. The two positions make different bets and both are exposed — which is why Part VII stakes this one on measurements with dates rather than on argument. First cited in §6.3.

E. P. Wigner. *The unreasonable effectiveness of mathematics in the natural sciences*, Comm. Pure Appl. Math. **13** (1960) 1.

Relevance. The essay on the unreasonable effectiveness of mathematics in the natural sciences: Wigner’s observation that the fit between mathematical structures invented for their own sake and the physical world is a gift we neither understand nor deserve. It stands behind this paper’s central claim, which is a specific instance of Wigner’s puzzle turned around — if the effectiveness is unreasonable when mathematics is applied to physics from outside, it is expected when the physics *is* the geometry and the integers are its topology. Whether that dissolves Wigner’s question or merely relocates it is a matter this paper raises honestly and does not claim to settle; Part X returns to it among the curious reader’s questions. First cited in §9.