Physics Without Time: A Tick-Based Reformulation of Fundamental Physics

Abstract

We present a systematic reconstruction of fundamental physics—classical mechanics, quantum mechanics, general relativity, and all forms of energy—using discrete ticks as the primitive ontological element. Ticks represent irreducible configuration updates; what we call "time" emerges only as a calibrated count of accumulated ticks. The master relation $E = \hbar\beta/\tau_0$ (energy equals Planck's constant times bits-per-tick divided by the calibration constant) provides a unified derivation of rest-mass energy, kinetic energy, thermal energy, chemical and nuclear binding energies, electromagnetic radiation, and gravitational potential energy. This reformulation reveals an informational substrate underlying all physical law, where spacetime curvature reflects spatial variation in distinguishability dynamics.

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1. Introduction

Contemporary physics treats time as a fundamental parameter—a continuous background against which dynamics unfolds. Yet time's ontological status remains deeply contested: general relativity geometrizes it, quantum mechanics parameterizes it asymmetrically, and thermodynamics gives it a preferred direction that the fundamental equations lack.

This document develops an alternative: **ticks as primitive, time as emergent**. A tick represents an irreducible micro-event—the smallest possible update to physical configuration. What we call "time" is not fundamental but emerges when we calibrate tick-counts against conventional measurement standards.

For the General Reader:

For over a century, physicists have written equations with "t" for time sitting right there as a basic ingredient—as fundamental as space, as real as matter. This document shows something surprising: **you can delete time from the foundations of physics entirely, and everything still works.**

Every equation in mechanics, quantum theory, thermodynamics, even Einstein's general relativity can be rewritten using only discrete "ticks"—countable updates to the universe's configuration—with no mention of time whatsoever. What we experience as the flow of time turns out to be bookkeeping: a way of labeling how many ticks have accumulated.

But there's a second surprise, arguably more profound. When you rewrite physics this way, **all forms of energy turn out to be the same thing.**

Think about how different energy seems in its various guises: the mass of a proton, the heat in a flame, the light from a star, the binding energy in a uranium nucleus, the gravitational pull of a planet. Physics students learn separate equations for each. But in the tick framework, every single one reduces to the same formula: $\mathbf{E = \hbar\beta/\tau_0}$. Energy is simply bits of distinguishability generated per tick, converted to conventional units.

Mass? That's how many bits per tick it takes to maintain a particle's identity. Heat? How many bits per tick a system explores as it jiggles. Light? How many bits per tick a photon oscillates through. Nuclear energy? The difference in bits per tick between one nuclear configuration and another. Gravity? A spatial gradient in how ticks map to what we call time.

One equation. Seven "different" energies. All expressible as the same phenomenon, viewed from different angles.

A caveat is warranted: for photons, this unification is derived—frequency genuinely maps to distinguishable phase states. For rest mass, the connection is currently more definitional than derived. "Identity maintenance" is an evocative metaphor awaiting operational grounding. The framework demonstrates that physics *can* be written this way; whether it *must* be—whether distinguishability is truly fundamental—remains an open question.

Still, the very fact that all of physics can be reformulated without fundamental time, with all energies expressible as bits-per-tick, suggests something deep: **information and distinguishability may be more fundamental than time, space, or energy themselves.** The universe, at bottom, might be generating distinctions, and everything else emerges from that.

The central insight is that energy, in all its forms, measures how many distinguishable configurations are generated per tick. A single master relation—$\mathbf{E = \hbar\beta/\tau_0}$—unifies the treatment of mass, motion, heat, chemical bonds, nuclear forces, electromagnetic radiation, and gravity. What conventionally appear as distinct energy types reduce to different manifestations of the same underlying quantity: bits per tick.

This reformulation accomplishes four objectives:

1. **Unification:** All forms of energy derive from a single informational primitive.
2. **Ontological clarity:** Classical mechanics, quantum mechanics, and general relativity emerge from a common discrete substrate.
3. **Resolution:** The puzzle of time's arrow dissolves—entropy increase counts ticks, not the reverse.
4. **Prediction:** The framework suggests observable signatures in quantum decoherence and gravitational phenomena at informational boundaries.

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2. Foundational Framework

2.1 Primitive Concepts

The fundamental ontology contains only two countable quantities:

Tick (n): An irreducible configuration update—the atomic unit of physical change. The universe's evolution can be indexed by an integer n that increments by one at each tick. Ticks are countable, discrete, and causally ordered within any local reference frame. In the fundamental ontology, there is no smaller sub-event. **Tick count is dimensionless—it is pure counting.**

For the General Reader: A tick is the universe's smallest possible "update"—the most basic thing that can happen. You can't have half a tick or a fraction of a tick. It's the indivisible atom of change itself. If you could observe the universe at the deepest level, you'd see it clicking forward one tick after another. Crucially, ticks aren't measured in seconds or any other unit—they're just counted, like counting steps.

Bit (b): A unit of objective physical distinguishability. One bit corresponds to a binary distinction resolvable by physical interaction. Importantly, one bit typically requires many ticks to emerge and stabilize, because the underlying micro-dynamics must explore, relax, and settle before a macro-distinguishable state exists. **Bit count is dimensionless—it is pure counting.**

For the General Reader: A bit here isn't just computer data—it's a real, physical distinction. It answers a yes/no question about the universe: Is the particle here or there? Is the spin up or down? Creating a reliably distinguishable answer takes work—many ticks must accumulate before the universe has "decided" enough that we can tell the difference. Like ticks, bits are just counted, not measured in conventional units.

Bits Per Tick (β): The fundamental ratio of distinguishable bits generated per tick:

$$\beta = \Delta b / \Delta n$$

This is a **dimensionless ratio**—pure number divided by pure number. It measures how many bits of distinguishability emerge per tick, without reference to any temporal concept.

For the General Reader: β (beta) is the heart of this framework. It's simply: how many distinguishable outcomes are generated per tick? High β means lots of distinguishability per tick—an active, energetic system. Low β means little distinguishability per tick—a quiet, cold system. Notice there's no mention of seconds or any time unit. We're comparing two counts: bits and ticks.

Ticks Per Bit (β^{-1}): The inverse ratio—how many ticks are required to generate one bit of distinguishability:

$$\beta^{-1} = \Delta n / \Delta b$$

Also dimensionless. High β^{-1} means bits are expensive (many ticks per bit); low β^{-1} means bits are cheap (few ticks per bit).

2.2 The Calibration Bridge

To connect with conventional physics, we introduce a **calibration constant** τ_0 that bridges tick-counts to the measurement conventions humans have developed:

$$t \equiv \tau_0 \cdot n$$

This is a **definition**, not a discovery. The quantity t (measured in seconds) is constructed from tick-counts via calibration. The constant τ_0 has dimensions of [time] only because it is the conversion factor to human measurement conventions.

For the General Reader: Humans have invented clocks, seconds, and hours. These are conventions—ways we've agreed to measure change. The calibration constant τ_0 is the bridge between the fundamental tick-count and our human conventions. It answers: "How many seconds correspond to one tick?" But this is our choice of description, not a fact about fundamental reality. At the deepest level, there are only tick-counts.

Critical distinction:

- **Fundamental level:** Only n (ticks) and b (bits) exist. Both dimensionless.
- **Emergent/calibrated level:** We define $t \equiv \tau_0 n$ to interface with measurement conventions.

The framework is time-free at its foundation. "Time" appears only when we choose to describe tick-counts using human conventions.

2.3 The Master Energy Relation

Energy measures how many distinguishable changes are generated per tick. The master definition:

$$E = \hbar\beta/\tau_0 = \hbar/(\tau_0\beta^{-1})$$

Dimensional analysis:

- β is dimensionless (bits/tick)
- $\hbar$ has dimensions [energy]·[time] = [action]
- τ_0 has dimensions [time] (calibration constant)
- Therefore E has dimensions [action]/[time] = [energy] ✓

For the General Reader: This is the central equation of the entire framework. It says that energy equals Planck's constant times the bits-per-tick ratio, divided by the calibration constant. More bits per tick means more energy. Fewer bits per tick means less energy. The calibration constant τ_0 and Planck's constant $\hbar$ are just conversion factors that translate the fundamental dimensionless ratio β into conventional energy units. The physics is entirely in β.

Derivation from established physics: Consider a photon with angular frequency ω (in conventional units). Quantum mechanics gives $E = \hbar\omega$. Now, ω measures oscillations per unit of conventional time. In the tick framework, one complete oscillation (2π phase progression) constitutes one bit of phase information, generated over some number of ticks.

On the bit convention: We adopt one bit per 2π phase progression as our convention. This choice is natural—2π represents one complete, distinguishable cycle—but other conventions would rescale all β values uniformly without changing the framework's structure. All numerical β values in this document should be understood as relative to this convention. The structure of the theory (energy unification, time emergence, gravitational effects) is convention-independent; only absolute numerical values depend on this choice.

If β_{photon} is the photon's bits-per-tick ratio under this convention, then:

$$\omega = \beta_{photon}/\tau_0$$

Thus:

$$\mathbf{E = \hbar\omega = \hbar\beta\_photon/\tau_0}$$

confirming the master relation. Planck's constant $\hbar$ (together with τ_0) converts the dimensionless information ratio into energy—grounding quantum mechanics in information theory.

2.4 The Emergence of Conventional Time

What we call "time" is constructed from tick-counts:

$$\mathbf{t = \tau_0 \cdot n}$$

For systems where the local tick-to-conventional-time conversion varies spatially (as in gravitational fields), we write:

$$\mathbf{dt = \tau_0 \cdot \alpha(x) \cdot dn}$$

where $\alpha(x)$ encodes how local distinguishability dynamics modulate the emergence of what we call "time." This immediately explains gravitational time dilation: regions with different $\alpha(x)$ yield different amounts of conventional time per tick.

For the General Reader: Here's a profound shift in perspective: "time" isn't a river that flows. It's a label we attach to tick-counts after calibration. Near a massive object like Earth or a black hole, the local calibration factor $\alpha(x)$ changes—more ticks are needed to produce each bit of distinguishability there. When we convert those tick-counts to conventional time, we find that "clocks run slower" near mass. But fundamentally, there are just ticks accumulating, with the local physics determining how many ticks yield each bit.

Important clarification: β is the fundamental bits-per-tick for a given process; α encodes how that maps to conventional time. In a gravitational well, we can treat β as fixed per tick, but $\alpha(r)$ changes the mapping to conventional time, so processes appear slower in t even though the underlying tick-by-tick evolution is unchanged.

2.5 Dimensional Analysis

The framework maintains a strict separation:

Fundamental Level (dimensionless):

Quantity	Symbol	Dimensions
Tick count	n	dimensionless
Bit count	b	dimensionless
Bits per tick	β	dimensionless
Ticks per bit	β^{-1}	dimensionless
Local scaling	α	dimensionless

Calibrated Level (conventional units):

Quantity	Symbol	Dimensions	Definition
Calibration constant	τ_0	[time]	Bridge to conventions
Conventional time	t	[time]	$t \equiv \tau_0 n$
Energy	E	[energy]	$E \equiv \hbar\beta/\tau_0$

The fundamental relation $E = \hbar\beta/\tau_0$ is dimensionally correct: [energy] = [action] × [dimensionless] / [time].

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3. Deriving All Forms of Energy

The master relation $E = \hbar\beta/\tau_0$ provides the backbone for a unified treatment of energy. Every form of energy—rest mass, kinetic, thermal, chemical, nuclear, electromagnetic, and gravitational—reduces to a specific manifestation of bits-per-tick dynamics.

For the General Reader: In standard physics, we learn about many different "types" of energy—kinetic energy, potential energy, thermal energy, nuclear energy, and so on. They seem quite different. But this section shows they're all the same thing in disguise: different ways of generating distinguishable configurations per tick. It's like discovering that what seemed like many different currencies are all just different denominations of the same underlying money.

3.1 Rest-Mass Energy

Einstein's rest-mass energy relation reads:

$E_{rest} = mc^2$

In the tick-based picture, every stable particle has an intrinsic informational load: to maintain its identity, the universe must continually update the particle's internal configuration tick by tick. This defines a baseline bits-per-tick ratio, β_{rest}, associated with the particle's rest state.

For the General Reader: Even a particle sitting perfectly still is doing something: it's maintaining its identity as *that particular kind of particle*. An electron isn't just an inert blob—it's a complex pattern that has to be continuously sustained tick by tick. Think of it like a juggler who must keep balls in the air. The heavier the particle, the more "juggling" is required—more bits per tick to maintain the pattern. This activity is what we call rest-mass energy.

But here's an honest admission: this "juggling" picture is currently a metaphor, not a derived result. For light, the connection between frequency and distinguishability is concrete. For mass, we're *defining* β to make the equation work, then interpreting that definition. The framework shows that rest-mass *can* be expressed as bits-per-tick; it doesn't yet prove that it *must* be.

By the master relation:

$$E_{rest} = \hbar\beta_{rest}/\tau_0$$

Equating with Einstein's expression:

$$mc^2 = \hbar\beta_{rest}/\tau_0$$

Solving:

$$\beta_{rest} = mc^2\tau_0/\hbar$$

Interpretation: β_rest measures how much distinguishability per tick is required to sustain the particle's identity. Heavier particles have larger β_rest—their identity is "expensive" in terms of bits per tick.

Honest assessment: Unlike the photon case, where β has clear operational meaning (oscillation frequency → distinguishable phase states), the rest-mass β is currently *defined* to make $E = \hbar\beta/\tau_0$ hold. The "identity maintenance" picture is evocative but metaphorical—a free electron in its rest frame has no obvious internal dynamics. Grounding β_rest in an independent informational principle would significantly strengthen this unification. This remains an open problem.

Candidate mechanisms for grounding β_rest: Several physical phenomena might provide independent derivations: (a) *Zitterbewegung*—the electron's intrinsic trembling motion at the Compton frequency $\omega_C = mc^2/\hbar$, which could represent genuine internal oscillation generating distinguishability; (b) *virtual pair fluctuations* in QFT, where the vacuum constantly probes the particle's identity through particle-antiparticle loops; (c) *internal degrees of freedom* in composite particles—protons have rich QCD dynamics with characteristic timescales that might map to β_rest. Demonstrating that any of these yields the correct β_rest from first principles, rather than from $E = mc^2$, would transform the energy unification from definitional to derived.

Worked examples:

Using $\tau_0 \approx 5.4 \times 10^{-44}$ s (Planck time):

(This choice is purely illustrative: τ_0 is an empirical calibration constant in the framework, not defined to equal the Planck time. In particular, the theory does not assume that a single tick corresponds to a Planck time, nor that ticks have any built-in spatial scale such as the Planck length.)

Particle	Mass	β_rest (bits/tick)
Electron	9.11×10^{-31} kg	4.2×10^{-23}
Proton	1.67×10^{-27} kg	7.7×10^{-20}
Higgs boson	2.23×10^{-25} kg	1.0×10^{-17}

For the General Reader: These numbers look tiny, but that's because we're measuring bits per single tick, and a tick is inconceivably brief. The ratios between particles are what matter: the Higgs boson requires about 130,000 times more bits per tick than the proton, reflecting its much greater mass.

Massless particles like photons have no rest frame and thus no rest β; they carry energy purely in their propagation and oscillation.

3.2 Kinetic Energy

Classical kinetic energy is:

$$E_k = \frac{1}{2}mv^2$$

In the tick-based ontology, we don't define velocity as distance per time. Instead, define **tick-displacement**:

$$\tilde{u} = \Delta x/\Delta n$$

This measures how much spatial configuration changes per tick—a ratio of displacement to tick-count, with dimensions of [length].

For the General Reader: When something moves, it's doing extra work beyond just maintaining its identity—it's also changing its position. Each tick, a moving object updates not just "what it is" but "where it is." This extra updating activity is kinetic energy. The more position-change per tick, the more energy. It's like the difference between a juggler standing still (rest-mass energy) and a juggler walking across the stage while juggling (rest-mass plus kinetic energy).

When an object moves with tick-displacement $\tilde{u}$, its total bits-per-tick increases beyond the rest value:

$$\beta_{total} = \beta_{rest} + \beta_{kin}$$

where β_{kin} is the additional bits-per-tick arising from motion. The total energy becomes:

$$E_{total} = \hbar(\beta_{rest} + \beta_{kin})/\tau_0 = mc^2 + E_k$$

Thus:

$$E_k = \hbar\beta_{kin}/\tau_0$$

Kinetic energy is the extra distinguishability generated per tick due to motion.

Relativistic refinement: The decomposition $\beta_{total} = \beta_{rest} + \beta_{kin}$ is a non-relativistic approximation. The exact relativistic relation is:

$\beta_{total} = \gamma \times \beta_{rest}$

where $\gamma = (1 - v^2/c^2)^{-1/2}$ is the Lorentz factor. As velocity approaches c, β_{total} diverges—consistent with unbounded kinetic energy at the speed of light.

3.3 Thermal Energy

For a single degree of freedom in thermal equilibrium, the average energy is:

$\langle E \rangle = \frac{1}{2}k_BT$

A system at non-zero temperature constantly explores new microstates. The higher the temperature, the more distinguishable configurations it samples per tick. This is precisely what β measures.

For the General Reader: Heat is jiggling. When something is hot, its atoms and molecules are bouncing around, constantly shifting between different arrangements. A hot cup of coffee has molecules careening into each other, producing new distinguishable configurations tick by tick. A cold ice cube has molecules barely moving, producing few new configurations per tick. Temperature directly measures a system's "restlessness"—its bits-per-tick of microstate exploration.

We therefore identify:

$E_{thermal} = \hbar\beta_{thermal}/\tau_0$

From equipartition:

$\frac{1}{2}k_BT = \hbar\beta_{thermal}/\tau_0$

Solving:

$\beta_{thermal} = k_BT\tau_0/(2\hbar)$

Worked examples:

Temperature	$\beta_{thermal}$ (bits/tick)
Room temp (300 K)	1.1×10^{-31}
Sun's surface (5,778 K)	2.0×10^{-30}
Sun's core (15×10^6 K)	5.3×10^{-27}

The sun's core generates about 50,000 times more bits per tick than room-temperature matter.

Absolute zero: As $T \to 0$, $\beta_{thermal} \to 0$. The system produces no distinguishability per tick—all thermal fluctuations cease.

3.4 Chemical Energy

Chemical energy arises from differences in electronic configurations between molecular states. The energy released or absorbed in a chemical reaction is:

$$\Delta E_{chem} = E_{products} - E_{reactants}$$

In tick language:

$$\Delta E_{chem} = \hbar(\beta_{products} - \beta_{reactants})/\tau_0$$

If a reaction is exothermic, then $\beta_{products} < \beta_{reactants}$: the products require fewer bits per tick to maintain their configurations. The difference in distinguishability per tick is released as heat or light.

For the General Reader: When you burn wood or digest food, you're rearranging atoms from one configuration to another. The starting configuration (wood + oxygen, or food + oxygen) is "expensive" to maintain—it requires a high bits-per-tick. The ending configuration (carbon dioxide + water + ash) is "cheaper"—it requires fewer bits per tick to sustain. The difference gets released as heat and light. Chemical reactions are fundamentally about finding lower-maintenance arrangements of atoms.

Interpretation: The universe "prefers" configurations that reduce informational maintenance burden (lower β). This is not a teleological claim but reflects the second law—systems evolve toward states requiring less distinguishability generation, shedding excess bits-per-tick as observable energy.

Typical scale: Chemical bonds involve ~1–10 eV per reaction:

$$\beta_{chem} \sim 10^{-28} \text{ bits/tick}$$

3.5 Nuclear Energy

Nuclear energy originates from changes in nucleon binding configurations. The mass-energy relation gives:

$$\Delta E_{nuclear} = \Delta m \cdot c^2$$

where Δm is the mass defect between initial and final states.

For the General Reader: Nuclear reactions are like chemical reactions but operating at a much deeper level—rearranging protons and neutrons inside atomic nuclei rather than electrons around atoms. The strong nuclear force that holds nuclei together is far more powerful than the electromagnetic force governing chemistry, so the energy scales are millions of times larger. When hydrogen nuclei fuse into helium in the sun, the resulting helium requires fewer bits per tick than the original hydrogen did—and the surplus is released as sunshine.

QCD describes extremely rich internal structure inside nucleons and nuclei. The informational content is enormous: the internal bits-per-tick associated with bound quarks and gluons far exceeds chemical configurations. When nuclei rearrange (fusion or fission), the internal β profile changes:

$$\Delta E\_nuclear = \hbar \Delta\beta\_internal/\tau_0$$

The mass defect Δm is how this change in β manifests in rest mass:

$$\Delta m \cdot c^2 = \hbar \Delta\beta\_internal/\tau_0$$

Scale comparison: Nuclear reactions involve ~1–10 MeV, roughly 10^6 times larger than chemical energies:

$$\beta\_nuclear \sim 10^{-22} \text{ bits/tick}$$

This reflects the vastly higher β of strong-force binding compared to electromagnetic binding.

Worked example—deuterium-tritium fusion:

- Mass defect: $\Delta m \approx 0.0189$ u $\approx 3.14 \times 10^{-29}$ kg
- Energy released: $\Delta E = \Delta mc^2 \approx 17.6$ MeV
- $\Delta\beta = \Delta E \cdot \tau_0/\hbar \approx 1.4 \times 10^{-21}$ bits/tick

The fusion products (helium-4 + neutron) require 1.4×10^{-21} fewer bits per tick than the reactants.

3.6 Electromagnetic Energy

Electromagnetic energy appears in quantized form (photons) and classical field form. Both reduce to bits per tick.

Photons: Quantum theory gives:

$$E\_photon = h\nu = \hbar\omega$$

In conventional units, frequency ν represents oscillations per unit conventional time. Each complete oscillation constitutes one bit of phase information. If a photon completes β_photon bits of phase per tick, then:

$$E\_photon = \hbar\beta\_photon/\tau_0$$

Higher-frequency photons have higher β_photon (more oscillatory distinguishability per tick), which is exactly what we observe as higher photon energy.

For the General Reader: Light is oscillating electromagnetic fields—waves that wiggle back and forth as they travel. The color of light corresponds to how much it oscillates per tick: violet light completes more oscillation-bits per tick than red light. Each oscillation produces one "bit" of distinguishable phase information. So violet light, with higher β, carries more energy. This is why ultraviolet light can cause sunburns while visible light cannot, and why X-rays can penetrate your body while radio waves bounce off.

Worked examples:

Photon type	β_photon (bits/tick)
Radio (FM)	3.4×10^{-35}
Visible (green, ~2 eV)	1.6×10^{-28}
X-ray	3.4×10^{-25}
Gamma ray	3.4×10^{-21}

Classical fields: The electromagnetic energy density is:

$$u_{EM} = \tfrac{1}{2}\varepsilon_0 E^2 + B^2/(2\mu_0)$$

Regions with large E and B represent high local bits-per-tick density:

$$u_{EM} \propto (\hbar/\tau_0) \times (\beta \text{ per unit volume})$$

The exact proportionality constant depends on the chosen mode decomposition and bit-assignment convention, but the structural identification of EM energy density with local β density remains.

The classical description emerges from coherent superposition of many photon modes, each contributing its β to the total.

3.7 Gravitational and Potential Energy

Gravitational potential energy for mass m at position x in potential Φ(x):

$$E_{pot} = m\Phi(x)$$

In the tick-based ontology, gravity modulates the local tick-to-conventional-time mapping across space via the scaling factor α(x). In a gravitational potential well, α differs from distant regions.

For the General Reader: Gravity doesn't just pull things—it changes how tick-counts map to conventional time. Near a massive object like Earth, the scaling factor α is smaller, so the same number of ticks corresponds to less conventional time. When we observe this, we say "clocks run slower" near mass. The potential energy you "have" when you're high up reflects your position in a region where α is closer to unity—where ticks map to conventional time more directly.

Important clarification: β remains the fundamental bits-per-tick for any given process. Gravity acts through α, which modulates how the underlying tick-by-tick evolution appears when converted to conventional time. A process with fixed β appears to proceed at different conventional "speeds" depending on the local value of α.

If α varies with position, then moving through a gravitational field changes how a mass's internal configuration appears in conventional time relative to its surroundings. The work required corresponds to traversing the α gradient.

Gravitational scaling profile (Schwarzschild geometry):

$$\alpha(r) = (1 - r_s/r)^{1/2}$$

where $r_s = 2GM/c^2$ is the Schwarzschild radius.

Physical interpretation: Deeper in the potential well, α decreases toward zero. Fewer conventional time units emerge per tick. The energy difference between two radii reflects the integrated α variation:

$$\Delta E_{pot} = (\hbar/\tau_0) \int \Delta\beta_{eff} \, d(\text{configuration})$$

where β_{eff} encodes how the fundamental β appears through the lens of spatially varying α.

Gravitational and other potential energies are manifestations of spatially varying α, encoded geometrically in the metric.

3.8 Unified Summary of Energy Types

Energy Type	Formula	β Interpretation	Typical β (bits/tick)
Rest mass	mc^2	Baseline identity maintenance	10^{-23}–10^{-17}
Kinetic	$\frac{1}{2}mv^2$	Additional β from motion	10^{-33}–10^{-23}
Thermal	$\frac{1}{2}k_BT$	Microstate exploration	10^{-31}–10^{-26}
Chemical	ΔH_{rxn}	Binding configuration difference	10^{-29}–10^{-27}
Nuclear	Δmc^2	Strong-force binding difference	10^{-23}–10^{-21}
Electromagnetic	$\hbar\omega$	Field oscillation	10^{-35}–10^{-19}
Gravitational	$m\Phi$	Spatial α gradient	varies with geometry

For the General Reader: This table is the payoff of the whole framework. Seven seemingly different kinds of energy—each with its own history, its own equations, its own textbook chapter—all turn out to be the same thing: bits per tick, dressed up in different costumes. Mass is identity maintenance. Heat is restlessness. Light is oscillation. Gravity is spatial variation in the tick-to-conventional-time mapping. One concept, seven manifestations.

Every form of energy is bits per tick, differing only in what structure changes and how that structure modulates distinguishability generation.

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4. Tick-Based Classical Mechanics

4.1 Kinematics

Replace all conventional derivatives with tick derivatives throughout classical mechanics.

Tick-displacement:

$$\tilde{u} = \Delta x/\Delta n$$

This has dimensions [length] since n is dimensionless. The standard velocity emerges only upon calibration:

$$v = dx/dt = (1/\tau_0)(dx/dn) = \tilde{u}/\tau_0$$

Tick-momentum:

$$\tilde{p} = m\tilde{u} = m(\Delta x/\Delta n)$$

Tick-impulse:

$$\tilde{F} = \Delta\tilde{p}/\Delta n$$

For the General Reader: Classical mechanics—Newton's laws of motion—can be completely rewritten in terms of ticks. Instead of asking "how much does position change per second?" we ask "how much does position change per tick?" Instead of "what force is acting?" (change in momentum per second), we ask "how much does momentum change per tick?" The equations look almost identical, but they're built on a different foundation. Conventional units appear only when we choose to calibrate.

4.2 Dynamics

Newton's second law in tick form:

$$\tilde{F} = m(\Delta^2 x/\Delta n^2)$$

For constant calibration, this reduces to standard mechanics upon substitution $t = \tau_0 n$.

Work-energy theorem:

$$\Delta E = \Sigma_n \tilde{F}_n \cdot \Delta x_n$$

Energy transfer occurs through tick-by-tick impulse applications—work is fundamentally discrete.

4.3 Conservation Laws

Noether's theorem translates directly: symmetries in tick-count correspond to conserved quantities.

- **Tick-translation invariance** → Energy conservation
- **Spatial translation invariance** → Momentum conservation
- **Rotational invariance** → Angular momentum conservation

The first is particularly significant: energy conservation reflects the principle that physics is the same at tick n and tick n+1—a discrete homogeneity in tick-count.

For the General Reader: One of the deepest results in physics is that conservation laws come from symmetries. Energy is conserved because physics works the same way at tick n as at tick n+1. Momentum is conserved because physics works the same here as it does over there. In the tick framework, energy conservation comes from something fundamental: the rules don't change from one tick to the next. The universe is consistent with itself across the most basic possible step.

4.4 Speed Without Time: Scenarios

In the tick framework, "speed" is not distance per unit time, but **distance per tick**. The fundamental quantity is the tick-displacement ũ:

$$\tilde{u} = \Delta x / \Delta n$$

This immediately raises two questions:

1. How do we compare speeds of different objects without using time?
2. How do we recover the usual notion of relative speed between observers?

We address both with simple scenarios.

4.4.1 Scenario 1: Comparing Two Moving Objects

Consider two objects A and B moving along a line. Over the same tick interval Δn, they undergo different displacements Δx_A and Δx_B:

$$\tilde{u}_A = \Delta x_A / \Delta n \ , \ \tilde{u}_B = \Delta x_B / \Delta n$$

If $\tilde{u}\_B > \tilde{u}\_A$, we say that B is "faster" than A: B covers more distance per tick than A.

No reference to clock time is needed. The comparison is purely combinatorial:

- Count ticks (Δn)
- Measure displacements (Δx)
- Compare the ratios

Conventional speeds v_A and v_B appear only after calibration:

$$v\_A = \tilde{u}\_A/\tau_0 \,,\ v\_B = \tilde{u}\_B/\tau_0$$

The ordering of speeds—who is faster—depends only on $\tilde{u}$, not on τ_0.

4.4.2 Scenario 2: Relative Speed Between Observers

Now consider two inertial observers, O and O′, each with their own tick counters n and n′ and their own spatial coordinates x and x′. In standard relativity, the Lorentz transformation relates (t, x) to (t′, x′). In the tick framework, we assume that:

- Each observer has a local mapping $t = \tau_0 n$, $t' = \tau_0 n'$ in their own frame.
- The usual Lorentz transformation connects (t, x) and (t′, x′).

The tick-displacement of a particle as seen by O is:

$$\tilde{u} = \Delta x/\Delta n$$

and as seen by O′:

$$\tilde{u}' = \Delta x'/\Delta n'$$

The conventional speeds in each frame are:

$$v = \tilde{u}/\tau_0 \,,\ v' = \tilde{u}'/\tau_0$$

The **relativistic velocity addition law** is then recovered entirely at the calibrated level, using τ_0 and the Lorentz transformation. The tick framework does not alter the algebra of relative speeds; it only removes fundamental time from the ontology. At the fundamental level, each observer simply counts ticks and measures displacements in their own coordinates.

4.4.3 Scenario 3: Light Speed as a Constraint on Tick-Displacement

For a photon, the conventional statement is:

$$v\_photon = c$$

In the tick framework:

$\tilde{u}$_photon = c · τ_0

If τ_0 is chosen to be of order the Planck time, $\tilde{u}$_photon becomes of order the Planck length per tick. But this is a **choice of calibration**, not a fundamental requirement. The key point is:

- The photon has the **maximal allowed tick-displacement** in the theory.
- No physical process can have $\tilde{u}$ > $\tilde{u}$_photon.

Thus the universal speed limit "nothing travels faster than light" becomes:

There exists a maximal tick-displacement $\tilde{u}$_max; photons saturate this bound.

The structure of special relativity is preserved. The difference is interpretational: the limit is now understood as a universal bound on how much spatial distinguishability can be generated per tick.

For the General Reader:

In ordinary physics, speed is "distance per second." Here, seconds don't exist at the fundamental level—only ticks and distances. So what does speed mean?

Imagine you're watching two cars on a track. You have a very fast camera that takes one frame per tick. You don't care how many seconds pass; you just count frames.

- Car A moves 1 cm between each frame.
- Car B moves 2 cm between each frame.

B is clearly faster than A, even though you never mentioned time. You only used:

- how far they moved per frame (per tick), and
- the fact that both were measured over the same number of frames.

That's what $\tilde{u} = \Delta x/\Delta n$ means: how much "real change" in position occurs per fundamental tick of the universe.

The speed of light becomes a limit on how much position-change you can pack into a single tick. Nothing can update its spatial configuration more per tick than a photon. When we later decide that "one tick corresponds to such-and-such seconds," we recover the usual value $c \approx 3 \times 10^8$ m/s—but the real story is about the maximum **change density per tick**, not about seconds.

4.4.4 Lorentz Structure from a Maximal Tick-Displacement (Outline)

In the analysis above, we assumed that once ticks are calibrated via $t = \tau_0 n$, the resulting variables transform according to the usual Lorentz relations. It is natural to ask whether this structure can itself be derived from the tick ontology.

In 1+1 dimensions, consider linear transformations between inertial frames:

$$n' = an + bx , \quad x' = cn + dx$$

motivated by homogeneity (no preferred origin in n or x) and the requirement that inertial frames related by constant relative motion map straight worldlines to straight worldlines. The tick framework postulates a maximal tick-displacement $\tilde{u}_{max}$ such that $|\Delta x| \leq \tilde{u}_{max} \Delta n$, with lightlike worldlines saturating this bound: $|\Delta x| = \tilde{u}_{max} \Delta n$.

Imposing that a lightlike worldline in one frame, $x = \pm\tilde{u}_{max} n$, is mapped to a lightlike worldline in any other frame, $x' = \pm\tilde{u}_{max} n'$, yields algebraic constraints on (a, b, c, d). Solving these constraints (together with relativity assumptions such as symmetry between frames) leads to the existence of an invariant quadratic form:

$$\mathscr{J} = (\tilde{u}_{max} \Delta n)^2 - (\Delta x)^2$$

preserved by all admissible transformations:

$$(\tilde{u}_{max} \Delta n')^2 - (\Delta x')^2 = (\tilde{u}_{max} \Delta n)^2 - (\Delta x)^2$$

Upon calibration with $t = \tau_0 n$ and $c = \tilde{u}_{max}/\tau_0$, this becomes the familiar Minkowski interval $c^2\Delta t^2 - \Delta x^2$, and the invariance group reduces to the usual Lorentz transformations.

In this sense, **Lorentz structure can be viewed as emerging** from the combination of:

1. A maximal tick-displacement $\tilde{u}_{max}$
2. Linearity (from homogeneity)
3. The relativity principle (symmetry between inertial frames)

rather than being fundamental in its own right.

A fully rigorous derivation in 3+1 dimensions, including discrete-to-continuum limits and the transformation properties of tick-counts under boosts, is left for future work and is discussed as an open problem in §9.5.

For the General Reader:

We claimed earlier that Lorentz transformations—the mathematical machinery of special relativity—work fine in the tick framework. But can we go further and actually *derive* them from ticks?

The answer is yes, at least in outline. The key ingredients are:

- There's a maximum amount of position-change possible per tick (photons saturate this).
- Physics looks the same regardless of which tick you call "tick zero" or where you place your spatial origin.
- Different observers moving relative to each other should agree on what counts as a lightlike (photon) trajectory.

From just these requirements, you can mathematically derive that there must exist a quantity—$(\tilde{u}_{max} \Delta n)^2 - (\Delta x)^2$—that all observers agree on. This is the tick-language version of the famous "spacetime interval" from relativity. When you translate back to conventional time units, you recover exactly the Lorentz transformations that Einstein discovered.

So special relativity isn't an add-on to the tick framework—it emerges naturally from the existence of a maximal tick-displacement.

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5. Quantum Mechanics in Tick Form

5.1 The Tick-Schrödinger Equation

Begin with the standard Schrödinger equation:

$$i\hbar(\partial\psi/\partial t) = H\psi$$

Substitute $t = \tau_0 n$, yielding $\partial/\partial t = (1/\tau_0)(\partial/\partial n)$:

$$i\hbar(1/\tau_0)(\partial\psi/\partial n) = H\psi$$

Multiply through by τ_0:

$$i\hbar(\partial\psi/\partial n) = \tau_0 H\psi = H_{tick}\,\psi$$

where the **tick-Hamiltonian** is:

$$H_{tick} = \tau_0 H$$

For the General Reader: Quantum mechanics describes how the "wave function"—a mathematical object encoding all possible states a system could be in—evolves. The Schrödinger equation is the master equation governing this evolution. Here we rewrite it in tick form: instead of asking how the wave function changes per unit conventional time, we ask how it changes per tick. The result is almost identical, just with a rescaled "Hamiltonian" (the operator encoding a system's energy). Quantum mechanics is perfectly compatible with discrete, tick-based evolution.

5.2 Physical Interpretation

The tick-Hamiltonian has dimensions [action] rather than [energy], reflecting that it generates evolution per tick rather than per unit conventional time. The eigenvalue equation:

$$H\_tick\ \psi_n = \mathscr{E}_n \psi_n$$

yields tick-energies $\mathscr{E}_n$ with dimensions of action. The standard energies emerge via:

$$E_n = \mathscr{E}_n/\tau_0$$

5.3 Discrete Evolution

The fundamental evolution is discrete, proceeding tick-by-tick:

$$\psi_{n+1} = \hat{U}\psi_n = \exp(-iH\_tick/\hbar)\psi_n$$

This is exact—not an approximation. The continuous Schrödinger equation emerges only in the limit of many ticks where smooth interpolation becomes valid.

Unitarity: Each tick-step preserves the norm $\langle\psi|\psi\rangle$, ensuring probability conservation at every discrete update.

For the General Reader: The wave function doesn't actually flow smoothly—it steps forward tick by tick, each step a precise mathematical operation. It's like a strobe light illuminating a dancer: between flashes, we don't see what happens, but each flash shows a well-defined position. The "smooth" evolution we usually talk about is just what emerges when we coarse-grain over many ticks. At the deepest level, quantum evolution is digital, not analog.

5.4 Worked Example: Harmonic Oscillator

Consider a quantum harmonic oscillator with $H = \hbar\omega(a^\dagger a + ½)$.

The tick-Hamiltonian becomes:

$$H\_tick = \tau_0\hbar\omega(a^\dagger a + ½)$$

For a photon-like oscillator where $\omega = \beta/\tau_0$:

$$H\_tick = \hbar\beta(a^\dagger a + ½)$$

The tick-evolution operator for one tick:

$$\hat{U} = \exp[-i\beta(a^\dagger a + ½)]$$

For the m-th energy eigenstate $|m\rangle$:

$$\hat{U}|m\rangle = \exp[-i\beta(m + ½)]|m\rangle$$

Each tick advances the phase by $\beta(m + ½)$ radians—the ground state acquires phase $-i\beta/2$ per tick, the first excited state acquires $-3i\beta/2$, and so forth.

5.5 Worked Example: Hydrogen Atom

The hydrogen ground state has energy $E_1 = -13.6$ eV. The corresponding bits-per-tick:

$$\beta\_H = |E_1|\tau_0/\hbar = (13.6 \text{ eV})(5.4 \times 10^{-44} \text{ s})/(6.58 \times 10^{-16} \text{ eV·s}) = 1.1 \times 10^{-27} \text{ bits/tick}$$

The electron's bound configuration generates about 10^{-27} bits of distinguishability per tick.

For the General Reader: A single hydrogen atom—just one proton and one electron—produces about 10^{-27} bits per tick. That sounds tiny, but remember we're measuring per single tick, and a tick is inconceivably brief. Over many ticks, this adds up: the electron is constantly "updating" its configuration around the proton, maintaining the intricate quantum dance that constitutes a hydrogen atom.

5.6 Measurement and Decoherence

In the tick framework, quantum decoherence corresponds to an event where environmental coupling dramatically increases the effective bits-per-tick of distinguishability generation. Pre-measurement, the superposition evolves unitarily. During decoherence:

1. The measuring apparatus couples to the system
2. Environmental interactions drive distinguishability generation
3. Interference terms become suppressed within $O(1)$ ticks

This connects to standard decoherence theory: the environment generates distinguishability more efficiently than the isolated system, suppressing quantum interference.

Important caveat: Decoherence explains why we don't observe superpositions—it suppresses interference terms. It does not, by itself, explain why a *particular* outcome occurs. The measurement problem concerns what "collapse" means ontologically, not merely how interference is suppressed. The tick framework currently offers a reformulation of decoherence dynamics, not a solution to the measurement problem. Whether rapid bit-generation has deeper implications for the ontology of measurement remains an open question.

For the General Reader: The mystery of quantum measurement—how a particle goes from "both here and there" to "definitely here"—has two parts. First: why don't we see quantum weirdness at everyday scales? Decoherence answers this—environmental interactions wash out quantum interference extremely quickly. The tick framework gives a natural language for this:

the environment floods the system with distinguishability. Second: why does one specific outcome occur rather than another? This deeper puzzle remains unsolved here, as it does in standard physics.

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6. General Relativity in Tick Form

6.1 The Informational Flux Tensor

Define the **informational flux tensor** J^{uv} encoding the flow of distinguishability through spacetime:

$$J^{uv} = \rho\_\beta\, u^u u^v + \mathcal{P}\_\beta\, g^{uv} + \pi^{uv}$$

where:

- ρ_β = bits per tick per unit volume (informational density)
- $\mathcal{P}\_\beta$ = informational pressure (distinguishability flux through surfaces)
- π^{uv} = anisotropic informational stress
- u^u = four-velocity of the informational rest frame

The stress-energy tensor relates to J^{uv} via:

$$T^{uv} = (\hbar/\tau_0)J^{uv}$$

This identification follows from $E = \hbar\beta/\tau_0$: energy density is $(\hbar/\tau_0)$ times bits-per-tick density.

For the General Reader: In general relativity, what curves spacetime is the "stress-energy tensor"—a mathematical object encoding where energy and momentum are located and how they're flowing. Here we reveal what this really is: it's proportional to the "informational flux tensor," which describes how distinguishability is distributed and flowing through space. Mass-energy curves spacetime because mass-energy *is* concentrated distinguishability production—regions of high β.

Transformation properties: J^{uv} transforms as a rank-2 tensor under coordinate transformations, ensuring covariance. The identification $T^{uv} = (\hbar/\tau_0)J^{uv}$ preserves this structure since $\hbar/\tau_0$ is a Lorentz scalar.

6.2 Einstein Equations in Informational Form

The Einstein field equations become:

$$G^{uv} = (8\pi G/c^4)T^{uv} = (8\pi G\hbar/c^4\tau_0)J^{uv} = \kappa(\hbar/\tau_0)J^{uv}$$

where $\kappa = 8\pi G/c^4$.

Interpretation: Spacetime curvature is proportional to the density of distinguishability generation. Mass-energy curves spacetime because it represents concentrated bit production per tick.

6.3 Gravitational Effects as α Variation

In a gravitational field, the local scaling factor α varies with position. Define α(r) as the gravitational redshift factor:

$$\boldsymbol{\alpha(r) \equiv (1 - r_s/r)^{1/2}}$$

where $r_s = 2GM/c^2$ is the Schwarzschild radius.

Physical meaning:

- At infinity: $\alpha \to 1$ (baseline calibration)
- As $r \to r_s$: $\alpha \to 0$ (conventional time emergence freezes)
- The tick-to-conventional-time relation is: $\boldsymbol{dt = \tau_0\, \alpha(r)\, dn}$

Near massive objects, $\alpha < 1$, so fewer conventional time units emerge per tick. When we convert tick-counts to conventional time, we find that "clocks run slower" near mass—this is gravitational time dilation, understood as α variation.

Important clarification on physical reality: In standard GR, gravitational time dilation is physical, not merely a coordinate effect—clocks near masses actually tick slower, as measured by the Pound-Rebka experiment and GPS corrections. The tick framework must be interpreted carefully here:

One interpretation: The tick-count n is a coordinate-like quantity, and α(r) encodes how physical proper time relates to this coordinate. Physical clocks measure $\tau_0\alpha(r)dn$, which is smaller per tick near masses.

Alternative interpretation: Ticks themselves are physically "slower" near masses (fewer per unit proper time as measured by a distant observer), and α encodes this physical slowing.

The framework as currently developed does not fully resolve which interpretation is correct, nor does it specify the relativistic transformation properties of tick-counts between frames. This remains an area requiring further theoretical development.

At the event horizon ($r = r_s$), $\alpha = 0$: no conventional time emerges per tick. From an external perspective, the horizon represents the boundary where the mapping to conventional time breaks down.

For the General Reader: As you approach a black hole, the scaling factor α shrinks toward zero—the conversion from ticks to conventional time becomes increasingly compressed. When we observe this, we say "clocks slow down." At the event horizon itself, α reaches zero: ticks continue, but no conventional time emerges from them at all. That's why nothing appears to cross the horizon from an external viewpoint—the mapping to our time coordinates breaks down completely.

Worked example—Earth's surface:

- $r_s(\text{Earth}) = 2GM/c^2 \approx 8.87$ mm $= 8.87 \times 10^{-3}$ m
- At Earth's surface ($r = 6.37 \times 10^6$ m):
- $r_s/r \approx 1.39 \times 10^{-9}$
- $\alpha(\text{surface}) = (1 - r_s/r)^{1/2} \approx 1 - (r_s/r)/2 \approx 1 - 6.95 \times 10^{-10}$

The scaling factor at Earth's surface is about 0.7 parts per billion smaller than at infinity—matching observed gravitational time dilation.

6.4 The Bianchi Identity Constraint

The Bianchi identities $\nabla_\mu G^{\mu\nu} = 0$ impose:

$$\nabla_\mu J^{\mu\nu} = 0$$

This is **informational conservation:** the total bits-per-tick generation is conserved through spacetime. Bits cannot be created or destroyed, only redistributed—a deep connection to the Bit Conservation and Balance (BCB) framework.

6.5 Worked Example: Schwarzschild Geometry

For a static, spherically symmetric mass M, the Schwarzschild metric in tick coordinates:

$$ds^2 = -\tau_0^2\alpha(r)^2 dn^2 + (1 - r_s/r)^{-1} dr^2 + r^2 d\Omega^2$$

where $\alpha(r) = (1 - r_s/r)^{1/2}$.

The tick-count relationship to coordinate time:

$$dn/dt = 1/(\tau_0\alpha(r))$$

- At infinity: $\alpha \to 1 \to dn/dt \to 1/\tau_0$ (baseline tick frequency)
- As $r \to r_s$: $\alpha \to 0 \to dn/dt \to \infty$ (ticks accumulate without advancing coordinate time)

Redshift derivation: A photon emitted at r_1 with bits-per-tick β_1 arrives at r_2. Conservation of the tick-phase progression gives:

$$\beta_2/\beta_1 = \alpha(r_1)/\alpha(r_2) = [(1 - r_s/r_1)/(1 - r_s/r_2)]^{1/2}$$

If $r_2 > r_1$ (photon climbing out of the well), then $\alpha(r_1) < \alpha(r_2)$, so $\beta_2 < \beta_1$: the photon loses bits-per-tick (redshifts). This reproduces the standard gravitational redshift formula, now understood as how β transforms across regions of varying α.

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7. Thermodynamic Connections

7.1 Entropy as Tick Counting

The second law of thermodynamics states that entropy increases. In the tick framework:

$$\Delta S = k_B \ln 2 \cdot \Delta b = k_B \ln 2 \cdot \beta \cdot \Delta n$$

The entropy production per tick:

$$\Delta S/\Delta n = k_B \ln 2 \times \beta$$

Entropy increase counts accumulated distinguishability. The arrow of entropy emerges from the arrow of tick-counting: ticks proceed forward by definition, and entropy accumulates accordingly.

For the General Reader: Entropy is often described as "disorder," but more precisely it counts how many distinguishable arrangements are compatible with what we observe. The second law says entropy always increases—systems evolve toward more distinguishable microstates. In the tick framework, this becomes: each tick produces more distinguishability, so entropy (which counts accumulated distinguishability) must increase.

But notice what happened: we haven't *explained* why entropy increases—we've *relocated* the question. Instead of asking "why does entropy always increase?" we now ask "why do ticks have a preferred direction?" The answer in this framework is that tick-directionality is taken as primitive—it's where we start, not something we derive. Whether this relocation represents progress is a matter of perspective: the puzzle hasn't vanished, but it's been moved to what may be more fundamental ground.

7.2 Temperature and Tick Dynamics

Temperature quantifies the bits-per-tick of thermal fluctuations. From Section 3.3:

$$T = 2\hbar\beta_{thermal}/(k_B\tau_0)$$

Hot systems have high β (many bits per tick); cold systems have low β (few bits per tick). Absolute zero corresponds to $\beta \to 0$: no distinguishability is generated, all fluctuations cease.

7.3 Landauer's Principle

Erasing one bit of information requires:

$$\Delta E_{min} = k_B T \ln 2 = 2\hbar \ln 2 \cdot \beta_{thermal}/\tau_0$$

(The factor of 2 arises from the equipartition-based definition of $\beta_{thermal}$; the essential physics is that erasure cost scales with thermal β.)

In tick terms: erasure requires coupling to a thermal reservoir whose bits-per-tick is sufficient to absorb the erased bit's distinguishability. The minimum energy cost reflects the β mismatch between information carrier and thermal bath.

For the General Reader: Landauer's principle is a profound connection between information and physics: erasing one bit of information—like clearing a computer memory cell—requires a minimum amount of energy, which gets dissipated as heat. In the tick framework, this makes perfect sense. A bit of information is a bit of distinguishability. To erase it, you must transfer that distinguishability to the environment. The environment can only absorb distinguishability at a certain bits-per-tick, so there's a minimum energy cost. Information isn't abstract—it has physical consequences.

7.4 The Second Law as Tick Accumulation

Why does entropy increase? In the tick framework, the question is reframed: ticks accumulate forward by definition. Each tick produces distinguishability; entropy counts accumulated bits.

This does not dissolve the puzzle of time's arrow—it relocates it. In standard physics, we ask "why does entropy increase?" In this framework, we ask "why do ticks have a preferred direction?" The answer here is that the forward direction of ticks is taken as primitive: ticks are defined to proceed in the direction of distinguishability production.

This is not circular but clarifying: many frameworks must take something as axiomatic. Here, the primitive is the directionality of tick-counting. The second law then follows as a consequence rather than standing as an independent mystery. Whether this relocation represents progress depends on whether the tick primitive proves more tractable than the entropy primitive—particularly for quantum gravity, where the nature of time is already deeply contested and taking distinguishability-generation as fundamental may offer new leverage.

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8. Experimental Signatures

8.1 Quantum Decoherence

The tick framework predicts that decoherence scales with environmental β:

$\Gamma_{decoherence} \propto \beta_{env}$

Systems coupled to high-β (high-energy, high-temperature) environments decohere with fewer ticks. This is testable:

1. **Temperature dependence:** Decoherence at 100 K vs. 300 K should differ by factor of ~3 in tick-count
2. **Gravitational dependence:** Systems in stronger gravitational fields (lower local α) should show modified decoherence behavior when measured in conventional time
3. **Energy-gap dependence:** Quantum systems with larger energy gaps (higher β) should show characteristic decoherence signatures

For the General Reader: Quantum superpositions—particles being "in two places at once"—are fragile. They "decohere" (collapse to definite states) when they interact with their environment. The tick framework predicts specific relationships: higher-temperature environments cause decoherence in fewer ticks. In regions of lower α (stronger gravity), decoherence appears modified when observed in conventional time. These predictions are testable with current or near-future technology.

8.2 Gravitational Boundaries

At interfaces where α changes sharply (e.g., near black hole horizons or potentially at cosmological boundaries), the framework predicts:

1. **Entropy accumulation:** Bits pile up where α decreases, analogous to traffic slowing at a bottleneck. This connects to black hole entropy scaling with horizon area.
2. **Modified Hawking radiation:** The emission spectrum should encode α gradients at the horizon. Temperature $T_H = \hbar c^3/(8\pi G M k_B)$ can be rewritten:

$T_H = 2\hbar\beta_{horizon}/(k_B\tau_0)$

where $\beta_{horizon}$ characterizes the horizon's distinguishability dynamics.

8.3 Discrete Structure Signatures

If ticks are truly fundamental, extremely precise experiments might detect discreteness. The relevant scale depends on τ_0:

$\tau_0 \sim t\_P \approx 5.4 \times 10^{-44}$ s (if Planck-scale calibration)

Current technology cannot probe this scale, but potential signatures include:

1. **Accumulated phase anomalies:** Interferometers running for many ticks might show phase drift from discrete tick structure
2. **Energy-tick uncertainty modification:** $\Delta E \cdot \Delta n \geq \hbar/(2\tau_0)$ with measurable differences at extreme precision
3. **Cosmological signatures:** The early universe's tick dynamics might leave imprints in the CMB or primordial gravitational waves

For the General Reader: If ticks are real—truly fundamental, not just a useful reformulation—there should be observable consequences. The tick duration is plausibly of order the Planck time (10^{-44} s) if τ_0 is chosen as a Planck-scale calibration, but the framework itself does not require this identification. Even if τ_0 differs from t_P by an order of magnitude, the relevant regime would remain far beyond current experimental reach. Indirect signatures might nonetheless be detectable: tiny accumulated errors in precision experiments, unexpected patterns in gravitational wave signals, or subtle anomalies in the cosmic microwave background. Finding such signatures would be revolutionary—direct evidence that "time" is fundamentally discrete.

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9. Discussion

9.1 Relationship to Other Approaches

The tick framework shares features with several research programs exploring discrete, informational, or emergent foundations for physics. A detailed comparison appears in §9.4; here we summarize the key distinctions:

Approach	Shared Features	Distinguishing Elements
Causal set theory	Discrete fundamental events	Ticks add informational content beyond causal order
Loop quantum gravity	Discretized spacetime	Ticks emphasize dynamics over kinematics; sidesteps problem of time
Digital physics	Computational metaphor	Ticks are physical events, not lattice-based automata
Entropic gravity	Information-theoretic foundations	Ticks provide substrate; gravity via α, not entropy gradients directly
Relational time	Time as emergent bookkeeping	Explicit quantification via β; unified energy treatment
It from bit	Information as fundamental	Concrete dynamical mechanism via $E = \hbar\beta/\tau_0$

Approach	Shared Features	Distinguishing Elements
Special relativity	Lorentz invariance	Lorentz structure emerges from maximal ũ (§4.4.4), not assumed

9.2 Ontological Status

Is the tick framework a reformulation or a new theory? At currently accessible scales, it reproduces standard physics exactly—every prediction matches. The value lies in:

1. **Conceptual unification:** A single primitive (ticks) underlies all energy types
2. **Ontological economy:** "Time" becomes derived rather than fundamental
3. **Research guidance:** Suggests where new physics might appear (Planck scale, horizons)

The framework becomes empirically distinguishable from standard physics only at scales where tick discreteness matters—likely near the Planck scale.

For the General Reader: Is this "just" a different way of writing the same equations, or does it reveal something genuinely new? At everyday scales—and even at the scales probed by our most powerful experiments—the tick framework makes exactly the same predictions as standard physics. It's a different *interpretation*, not a different theory (yet). But interpretations matter. They guide where we look for new physics, suggest which problems are "real" and which are artifacts of our formalism, and shape how we think about the universe. And if ticks are truly fundamental, the framework should eventually make different predictions at extreme scales.

9.3 Open Questions

1. **Tick synchronization and Lorentz structure:** Section 4.4.4 outlines how Lorentz transformations emerge from a maximal tick-displacement in 1+1D. Extending this to 3+1D and understanding how tick-counts transform under boosts remains open. Does entanglement involve shared tick structure across spacelike separations?
2. **Quantum gravity:** Does the framework naturally regularize gravitational divergences by providing a minimum β^{-1}?
3. **Cosmological implications:** What sets the universe's initial β distribution? Is cosmic inflation a period of extremely high β?
4. **Consciousness:** Does subjective experience require a minimum bits-per-tick threshold? Is awareness tied to distinguishability generation?
5. **The void:** In the broader VERSF framework, what is the β of the underlying void substrate? Is $\beta_{void} = \infty$ or undefined?

9.4 Related Works

Several research programs have explored the possibility that spacetime, time flow, or gravitational dynamics arise from deeper informational or discrete structures. While sharing conceptual motivations with these approaches, the present tick-based framework differs in scope, ontology, and mathematical structure.

Causal Set Theory (Bombelli, Sorkin et al.)

Causal set theory posits that spacetime is fundamentally discrete and partially ordered, with the continuum emerging from a dense causal graph. While both approaches reject continuous time, causal sets take causal order as primitive. The tick framework instead takes distinguishability generation as primitive and derives temporal and geometric structure from the bits-per-tick (β) rather than from causal links.

Loop Quantum Gravity (Rovelli, Smolin, Ashtekar)

LQG quantizes geometric observables, leading to discrete spectra for areas and volumes. However, it retains time as a problematic parameter in the "problem of time." The tick framework differs fundamentally by treating neither geometry nor time as primary. Instead, geometry and time both emerge from informational dynamics (β) and gravitational scaling (α), sidestepping the canonical-time problem entirely.

Digital Physics and Cellular Automaton Models (Zuse, Fredkin, 't Hooft)

Digital physics proposes that the universe operates like a cellular automaton at the smallest scales. The tick framework shares the idea of discrete updates but does not assume a spatial lattice, local update rules, or a pre-existing clock. Instead, the tick is a dimensionless counter of configuration updates, and all physical structure emerges only after calibration via τ_0.

Entropic and Emergent Gravity (Jacobson, Verlinde)

Jacobson showed that Einstein's field equations can be viewed as an equation of state, and Verlinde proposed that gravity arises from entropic forces. These approaches connect gravity to information and thermodynamics. The tick framework shares this spirit but introduces a more primitive underlying quantity—bits-per-tick (β)—from which energy, entropy increase, and gravitational redshift all derive uniformly. Here gravity emerges not from entropy gradients directly but from spatial variations in the α-scaling between ticks and conventional time.

Relational and Emergent-Time Approaches (Rovelli, Barbour)

Relational approaches treat time as an emergent bookkeeping of change, not as a fundamental dimension. The tick-based model aligns with this philosophy but goes further by quantifying change explicitly as bits of distinguishability per tick, allowing energy, temperature, decoherence, and gravitational time dilation to be re-expressed in the same informational variables.

Quantum Information Foundations of Physics (Wheeler, Zeilinger, Hardy)

Wheeler's "it from bit," Zeilinger's informational principles, and Hardy's operational reconstructions of quantum theory all propose that physical laws emerge from constraints on information. The present framework is compatible with this lineage but offers a concrete dynamical substrate—ticks—and a universal quantitative link: $E = \hbar\beta/\tau_0$. This provides an explicit mechanism for how information generation governs dynamics, rather than relying on axioms alone.

Summary

Across these diverse programs, the common thread is the search for a deeper foundation beneath spacetime and quantum fields. The tick-based formulation contributes a unifying perspective: the bits-per-tick at which the universe generates distinguishable configurations (β) serves as common currency behind mass, motion, heat, radiation, binding forces, gravity, entropy, and the emergent flow of time. Where other approaches posit new structure (causal links, spin networks, entropic forces), the tick formulation expresses them through a single informational primitive coupled to a calibration constant—though, as discussed in §9.5, significant theoretical work remains to fully realize this program.

9.5 Limitations and Honest Assessment

This document presents a reformulation of known physics, not new predictions at currently accessible scales. Several aspects of the framework require further development or involve choices that should be made explicit:

1. The rest-mass β is definitional, not derived.

The derivation of $E = \hbar\beta/\tau_0$ from photon physics ($E = \hbar\omega$) is clean: β has clear operational meaning as oscillation frequency mapping to distinguishable phase states. But extending this to rest mass involves a conceptual leap.

For a free electron in its rest frame, what does "updating its internal configuration tick by tick" mean operationally? The electron just *is*—it has no obvious internal dynamics. The "identity maintenance" language is evocative but metaphorical.

Currently, $\beta\_rest = mc^2\tau_0/\hbar$ is *defined* to make $E = \hbar\beta/\tau_0$ hold for rest-mass energy. This makes the unification tautological at present. The framework would be significantly strengthened by deriving β_rest from an independent informational principle—candidate mechanisms include Zitterbewegung (internal oscillation at the Compton frequency), virtual pair fluctuations, or internal QCD dynamics in composite particles (see §3.1). This remains an open problem.

2. The status of τ_0 is unresolved.

The document uses $\tau_0 \approx t\_P$ (Planck time) for all numerical examples while calling it an "empirical calibration constant" that is "purely illustrative." These positions are in tension.

Three possibilities exist:

- $\tau_0 = t\_P$ by theoretical necessity (but no argument for this has been given)
- τ_0 is empirically determined (but no measurement to fix it has been proposed)
- τ_0 is a free parameter (which should be acknowledged explicitly)

The striking result $\beta = 1$ at Planck energy depends entirely on choosing $\tau_0 = t\_P$. If $\tau_0 \neq t\_P$, this "saturation" interpretation dissolves. The framework currently treats τ_0 as a free parameter, with $\tau_0 \approx t\_P$ being a natural but not required choice.

3. The bit convention is more significant than acknowledged.

The choice "one bit per 2π phase progression" determines all numerical β values. Is there a principled reason for this choice?

Possible justifications:

- Information-theoretic: 2π represents one complete distinguishable cycle
- Quantum-mechanical: relates to $\hbar$ normalization conventions
- Arbitrary: just a choice of units

If arbitrary, all β values should be understood as defined relative to this convention. Different conventions would rescale all β values uniformly without changing the framework's structure, but would change numerical predictions for any quantity depending on absolute β values.

4. Relativistic transformation properties are partially addressed.

The document states ticks are "causally ordered within any local reference frame." Section 4.4.4 outlines how Lorentz structure can emerge from the maximal tick-displacement postulate in 1+1 dimensions: the invariant quadratic form $\mathscr{J} = (\tilde{u}\_max\ \Delta n)^2 - (\Delta x)^2$ arises naturally from requiring that lightlike worldlines remain lightlike under frame changes.

However, several questions remain for a complete treatment:

- The full 3+1 dimensional derivation with spatial isotropy
- Discrete-to-continuum limits: how does the continuous Lorentz group emerge from discrete tick-counts?
- The transformation of tick-counts themselves under boosts: if O and O′ are in relative motion, how do their tick-counters relate?

The 1+1D outline shows the approach is viable; completing it rigorously is future work.

5. Gravitational effects require clarification.

Standard GR treats proper time as physical—clocks near masses actually tick slower (Pound-Rebka experiment, GPS). The tick framework's treatment via $\alpha(x)$ risks conflating coordinate effects with physical effects. Whether ticks themselves slow down in gravitational wells, or whether α merely encodes a coordinate mapping, needs resolution. See §6.3 for further discussion.

6. Experimental predictions remain qualitative.

The decoherence signatures mentioned in §8 are promising but vague. A specific quantitative prediction distinguishing tick-based decoherence from standard decoherence theory would significantly strengthen the framework's empirical content.

Summary: The framework successfully demonstrates that known physics can be reformulated without fundamental time, using bits-per-tick as a unifying concept. However, the unification is currently more definitional than derived (especially for rest mass), and several foundational questions—the value of τ_0, relativistic transformation properties, the physical interpretation of gravitational effects—require further theoretical development.

9.6 Perception, Subjective Time, and Change Density

The tick framework has implications not only for fundamental physics but also for how we think about perception and subjective experience. If the universe's underlying dynamics are best described in terms of bits-per-tick (β), then brains—being physical systems—must be **sampling and transforming change density**, not continuous time.

In conventional thinking:

- Time is a flowing parameter.
- The brain "experiences" this flow and builds a representation of events laid out along it.

In the tick framework:

- There is no fundamental time to "flow".
- The brain receives **streams of discrete changes** in sensory inputs.
- These are compressed, filtered, and integrated into **patterns of distinguishability**—internal β-profiles across neural populations.

9.6.1 Subjective Time as Perceived β

Subjective time—how fast or slow a moment feels—may be more closely related to **perceived change density** than to any external clock. Consider:

- In high-change environments (e.g., emergencies, accidents), people often report that "time slowed down."
- In low-change environments (e.g., waiting rooms, mindless scroll), time seems to drag while it passes quickly on the clock.
- In flow states, time can seem to vanish despite a high density of structured activity.

In a tick-based interpretation, subjective time may track something like:

β_brain = Δb_neural / Δn_phys

the number of *internally distinguishable* neural states generated per physical tick. Two regimes emerge:

1. **High external β, matched internal compression.** The environment changes significantly, and the brain is efficiently encoding those changes (e.g., in a focused, engaged state). Subjective time may feel rich but not stretched.
2. **High external β, poor internal compression.** Overwhelming, novel, or threatening situations force the brain to process an unusually large number of salient distinctions per tick. Subjective time may feel expanded ("things slowed down") because the brain is generating an unusually high density of distinguishable internal states per tick.

Conversely, when external β is low (monotony) or the brain filters most changes as irrelevant, the internal β_brain may drop even while many ticks pass. Subjectively, "nothing happens," and time feels strange—either dragging (boredom) or disappearing (mind-wandering).

9.6.2 Reality as a Change-Density Interface

If perception is fundamentally about managing β, then our picture of "reality" becomes:

- The world is not experienced as a smooth function of t, but as a structured sampling of **change-density patterns** across sensory channels.
- The brain implements a kind of **adaptive β-matching**: amplifying relevant changes, compressing redundant ones, ignoring microscopic fluctuations.
- Different species, and different brain states, effectively live at different **β-resolutions**—they are tuned to different regimes of change density.

From this perspective, "what is real" for an organism at any moment is:

The subset of physical distinguishability that its nervous system can track as β, given its evolutionary design and current state.

This challenges naive realism about perception. The brain is not passively watching a movie running in time; it is dynamically constructing a representation of change density that is constrained by its own informational limits. Two observers in the same physical spacetime region may inhabit very different **β-realities**—one saturated with distinctions, the other almost featureless.

9.6.3 Altered States and β Modulation

Psychedelic states, meditative states, and extreme emotional states are often described in terms of time distortion, enhanced or diminished detail, and changes in the felt "granularity" of experience. In the tick framework, these phenomena can be tentatively interpreted as changes in:

- **β_in:** how much sensory change is allowed in (gating)
- **β_proc:** how many internal distinctions the brain generates per tick (processing)
- **β_out:** how much of this is accessible to conscious report

For example:

- **Hyper-awareness / over-stimulation:** β_in and β_proc are high; the brain cannot compress efficiently. Experience feels "thick," detailed, or slowed.
- **Sedation / monotony:** β_in and β_proc are low; the brain's state changes little per tick. Experience feels thin, boring, or absent.
- **Flow states:** β_in is high but β_proc is optimized; many changes are handled efficiently, leading to a sense of effortlessness and temporal distortion ("time flew by").

These interpretations are speculative and lie outside the core physics content. However, they illustrate how the tick framework naturally extends into a theory of perception:

- **Subjective time** becomes perceived change density, not an internal clock mirroring an external t.
- **Conscious experience** becomes a structured sampling of β across nested neural systems.
- **Cognitive limits** become informational limits on how much β can be handled per tick.

For the General Reader:

If the universe is really ticking forward by generating bits of distinguishability, then your brain is not experiencing "time" in the usual sense—it's experiencing **change density**.

- When a lot of relevant things change per tick, your experience feels rich, intense, or slow.
- When very little changes per tick, your experience feels empty, dull, or timeless.
- Different brain states (alert, tired, frightened, meditative, intoxicated) may correspond to different ways of tuning into β.

In other words, your sense of time may be your brain's way of tracking how much change it's managing per tick—not a direct perception of an underlying time variable. The tick framework doesn't prove this, but it gives a clean language for thinking about it—and suggests that perception, like physics, may ultimately be about distinguishability rather than time itself.

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10. Conclusion

By replacing continuous time with discrete ticks, we achieve a unified description of all physics—mechanics, quantum theory, gravitation, thermodynamics, and every form of energy. The key results:

1. **Master relation:** $E = \hbar\beta/\tau_0$ unifies all energy types as manifestations of bits-per-tick.
2. **Energy unification:**
    - Mass is baseline identity maintenance in bits-per-tick
    - Kinetic energy is additional β from motion
    - Thermal energy is microstate exploration β

    - Chemical and nuclear energies are binding-configuration β differences
    - Electromagnetic energy is field oscillation β
    - Gravitational energy reflects spatial α variation
3. **Conventional time emergence:** $dt = \tau_0\alpha(x)dn$, where τ_0 is the calibration constant and α encodes local gravitational effects.
4. **Gravity as geometry:** Curvature reflects informational flux; gravitational effects arise from α variation.
5. **Entropy as counting:** The second law expresses forward tick accumulation.
6. **Bit conservation:** $\nabla\_\mu J^{uv} = 0$ ensures distinguishability is redistributed but never created or destroyed.

For the General Reader: We started with a simple idea—what if "time" isn't fundamental, but emerges from something deeper? The answer we found is that *distinguishability* may be fundamental. The universe, at its core, could be generating distinctions, ticking forward through configurations that can be told apart. Energy measures how many bits per tick. "Time" is how we label accumulated ticks after calibration. Gravity warps the calibration factor. Entropy counts the total. What seemed like many separate phenomena—mass, motion, heat, light, gravity—turn out to be expressible as one phenomenon viewed from different angles.

But intellectual honesty requires noting what we haven't done. The unification of energy types is currently more definitional than derived—especially for rest mass, where "identity maintenance" is a metaphor awaiting operational grounding. The calibration constant τ_0 remains a free parameter. The relativistic transformation properties of ticks are underdeveloped. And the arrow of time hasn't been explained—just relocated from "why does entropy increase?" to "why do ticks have a direction?"

Whether this reformulation ultimately reveals new physics, provides profound conceptual clarity, or merely offers an elegant repackaging of known results remains to be seen. Its value lies in suggesting that information and distinguishability might be more fundamental than time itself—a perspective that could guide the search for quantum gravity.

This framework does not replace standard physics—it reveals a possible informational substrate. The equations remain valid; their interpretation shifts from time-parameterized evolution to tick-by-tick distinguishability generation. Whether ticks represent fundamental reality or a powerful conceptual tool, the reformulation illuminates deep connections between information, energy, thermodynamics, and spacetime geometry—while honestly acknowledging the work that remains.

Appendix A: Notation Summary

Fundamental Level (dimensionless):

Symbol	Meaning
n	Tick count
b	Bit count
β	Bits per tick (= $\Delta b/\Delta n$)
β^{-1}	Ticks per bit (= $\Delta n/\Delta b$)
α	Local gravitational scaling factor

Calibrated Level (conventional units):

Symbol	Meaning	Dimensions
τ_0	Calibration constant	[time]
t	Conventional time	[time]
$\tilde{u}$	Tick-displacement	[length]
$\tilde{p}$	Tick-momentum	[mass]·[length]
$\tilde{F}$	Tick-impulse	[mass]·[length]
H_tick	Tick-Hamiltonian	[action]
$\mathscr{E}$	Tick-action	[action]
J^{uv}	Informational flux tensor	$[\text{length}]^{-4}$
ρ_β	Bits-per-tick density	$[\text{length}]^{-3}$
$\mathcal{P}$_β	Informational pressure	$[\text{length}]^{-3}$

Appendix B: Key Relations

Master energy relation:

$E = \hbar\beta/\tau_0$

Rest-mass β:

$\beta\_rest = mc^2\tau_0/\hbar$

Thermal β:

$\beta\_thermal = k\_BT\tau_0/(2\hbar)$

Conventional time emergence:

$dt = \tau_0\ \alpha(x)\ dn$ *(for constant α in a region: $t = \tau_0\alpha n$)*

Tick-Schrödinger equation:

$i\hbar(\partial\psi/\partial n) = H\_tick\ \psi$

Discrete evolution:

$\psi_{n+1} = \exp(-iH\_tick/\hbar)\psi_n$

Einstein equations (informational form):

$G^{uv} = \kappa(\hbar/\tau_0)J^{uv}$

Gravitational scaling:

$\alpha(r) = (1 - 2GM/rc^2)^{1/2}$

Tick-to-coordinate-time relation:

$dn/dt = 1/(\tau_0\alpha(r))$

Gravitational redshift:

$\beta_2/\beta_1 = \alpha(r_1)/\alpha(r_2)$

Entropy-tick relation:

$\Delta S/\Delta n = k\_B \ln2 \times \beta$

Photon β:

$\beta\_photon = \omega\tau_0$

Tick-space interval (1+1D):

$\mathcal{J} = (\tilde{u}\_max\ \Delta n)^2 - (\Delta x)^2$ *(Lorentz-invariant; see §4.4.4)*

Appendix C: Characteristic β Values

Derivation method:

All β values are computed from the master relation:

$\boldsymbol{\beta = E\tau_0/\hbar}$

using:

- $\tau_0 \approx 5.391 \times 10^{-44}$ s (Planck time)

- $\hbar \approx 1.055 \times 10^{-34}$ J·s

For thermal systems, $\beta\_thermal = k\_BT\tau_0/(2\hbar)$, which includes the equipartition factor of ½.

Worked examples:

Electron rest mass:

- E = 0.511 MeV = 8.19×10^{-14} J
- $\beta = (8.19 \times 10^{-14}\text{ J})(5.391 \times 10^{-44}\text{ s})/(1.055 \times 10^{-34}\text{ J·s}) = 4.2 \times 10^{-23}$

Room temperature (300 K):

- $k\_BT = (1.381 \times 10^{-23}\text{ J/K})(300\text{ K}) = 4.14 \times 10^{-21}$ J
- $\beta = (4.14 \times 10^{-21}\text{ J})(5.391 \times 10^{-44}\text{ s})/(2 \times 1.055 \times 10^{-34}\text{ J·s}) = 1.1 \times 10^{-31}$

Planck energy:

- $E\_P = \sqrt{(\hbar c^5/G)} = 1.956 \times 10^9$ J
- $\beta = (1.956 \times 10^9\text{ J})(5.391 \times 10^{-44}\text{ s})/(1.055 \times 10^{-34}\text{ J·s}) = 1.0$

Reference table:

System	Energy Scale	Energy (J)	β (bits/tick)
Electron rest mass	0.511 MeV	8.19×10^{-14}	4.2×10^{-23}
Proton rest mass	938 MeV	1.50×10^{-10}	7.7×10^{-20}
Room temperature	26 meV	4.14×10^{-21}	1.1×10^{-31}
Visible photon	2 eV	3.20×10^{-19}	1.6×10^{-28}
Chemical bond	1–10 eV	10^{-19}–10^{-18}	10^{-28}–10^{-27}
Nuclear binding	1–10 MeV	10^{-13}–10^{-12}	10^{-23}–10^{-22}
Planck energy	1.22×10^{19} GeV	1.96×10^9	1.0

Note: At the Planck energy, β = 1 exactly—one bit per tick. This is not a coincidence but follows from the definition of Planck units, where $\hbar$, G, and c combine to give natural units. This may represent a fundamental limit where each tick produces exactly one bit of distinguishability, suggesting that Planck-scale physics saturates the information-generation capacity of a single tick. However, this observation relies on choosing $\tau_0 \approx t\_P$ as a natural calibration; the framework itself does not require ticks to be Planck-scale in duration or tied to the Planck length.

Appendix D: Clarifications on α, β, τ_0, and Interpretive Structure

This extended appendix expands on four key conceptual areas of the Tick-Based Physics framework:

(1) the interplay between the gravitational scaling factor α and the bits-per-tick ratio β,

(2) the physical meaning and derivation pathway for the rest-mass β,

(3) the conceptual and practical role of the calibration constant τ_0,

and (4) the interpretive placement of perception-related material.

The purpose is to give deeper explanation, clearer operational meaning, and explicit worked examples to address potential reviewer concerns.

D.1 The α–β Interplay in Gravitational Settings

In the main text, two quantities govern how processes unfold:

• β — the *fundamental* rate at which a system generates distinguishable physical states per tick.

• α(r) — the *gravitational scaling factor* that determines how tick-counts map to locally measured proper time.

A recurring question is: Does gravity change β, α, or both?

The framework adopts the following position:

β is invariant for a given physical process.

α(r) modifies how tick-counts appear when interpreted as proper time.

Thus, in a gravitational well, clocks do not physically produce fewer bits per tick; rather, observers at different gravitational potentials assign different amounts of proper time to each tick.

This distinction is crucial because gravitational time dilation is a *measured physical effect*, not an artefact of coordinates.

D.1.1 Step-by-Step Physical Interpretation

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1. A system produces β bits per tick at the fundamental level.

   This is independent of gravity and reflects the microphysical identity of the system.

2. Proper time measured by a local observer emerges via:

   $d\tau = \tau_0 \cdot \alpha(r) \cdot dn$

3. Therefore, the observed rate of physical processes depends on α(r).

   If $\alpha(r) < 1$ (deeper gravitational well), then:

   each tick corresponds to *less* proper time.

4. Observers compare frequencies, decay rates, or oscillations with respect to their local proper time τ. Therefore a process with fixed β appears slower where α is smaller.

This model preserves:

• the *physicality* of gravitational redshift,

• the invariance of β as a microscopic generator of dynamics,

• the interpretation of α as a geometric-gravitational modifier.

D.1.2 Worked Example: Gravitational Redshift in Explicit Tick Bookkeeping

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Consider a photon emitted at radius r_1 and received at radius r_2.

A photon's β is constant:

$\beta\_photon = constant$

A local observer measures frequency as:

$\nu(r) = \beta\_photon / (\tau_0 \cdot \alpha(r))$

Thus:

$\nu_1 = \beta\_photon / (\tau_0 \cdot \alpha(r_1))$

$\nu_2 = \beta\_photon / (\tau_0 \cdot \alpha(r_2))$

The gravitational redshift is:

$\nu_2 / \nu_1 = \alpha(r_1) / \alpha(r_2)$

For Schwarzschild geometry:

$\alpha(r) = \sqrt{(1 - 2GM / (r \cdot c^2))}$

Thus:

- If $r_2 > r_1$ (photon climbing upward), then $\alpha(r_2) > \alpha(r_1)$, so $\nu_2 < \nu_1$.
- This reproduces the standard gravitational redshift exactly.

What this clarifies:

- β does *not* need to change to produce redshift.
- α fully accounts for the observed energy shift.
- The tick-interpretation remains compatible with Pound–Rebka and GPS experiments.

D.1.3 Why β Must Remain Invariant for a Photon

If β changed with gravitational potential:

- energy conservation along null geodesics would break,
- photons could spontaneously gain or lose intrinsic distinguishability,
- the redshift formulas would depend on microscopic assumptions about β.

By treating β as invariant:

• gravitational redshift arises from α-scaling alone,

• the framework aligns with the geometric interpretation of GR,

• measurable frequencies remain tied to locally emergent proper time.

This offers a clean informational reinterpretation of gravitational phenomena.

D.2 Rest-Mass β: Toward a More Explicit Physical Interpretation

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The rest-mass relation:

$$\beta\_rest = (m \cdot c^2 \cdot \tau_0) / \hbar$$

is the least-derived component of the theory. This appendix provides a more concrete pathway for grounding β_rest in physical dynamics.

D.2.1 Why Rest-Mass Must Correspond to a Nonzero β

A particle with rest mass m has:

• an invariant internal energy mc^2,

• a characteristic Compton frequency ω_C,

• field-theoretic structure maintaining its quantum identity.

Even at rest, such a particle is not “doing nothing.”

It sustains itself as a stable configuration of fields, and this maintenance plausibly corresponds to the production of at least one bit of distinguishability over some intrinsic cycle.

Thus, a nonzero β_{rest} is physically motivated.

D.2.2 Zitterbewegung-Based Derivation Sketch

The electron exhibits rapid internal oscillations with Compton frequency:

$\omega_C = (m \cdot c^2) / \hbar$

$T_C = 2\pi\hbar / (m \cdot c^2)$

If we posit that each Compton cycle yields one distinguishable state (one bit), then:

$\beta_{rest} \approx \tau_0 / T_C$

$= (m \cdot c^2 \cdot \tau_0) / (2\pi\hbar)$

Ignoring the 2π (which depends on bit conventions), this matches the main text:

$\beta_{rest} = (m \cdot c^2 \cdot \tau_0) / \hbar$

Implications:

• This gives β_{rest} an *operational meaning*.

• Mass corresponds to the information required to maintain identity.

• The internal oscillation picture fits naturally into the tick framework.

This is not yet a derivation from first principles but provides a viable methodological route.

D.3 The Status of τ_0: A Unified and Explicit Position

To avoid ambiguity, we adopt a single, clear stance:

$\tau_0 = t\_P$ (the Planck time)

Reasons for this choice:

1. t_P is the unique timescale constructed solely from $\{G, \hbar, c\}$.

2. It marks the threshold where classical geometry and quantum fluctuations intersect.

3. Using $\tau_0 = t\_P$ ensures that $\beta = 1$ corresponds exactly to the Planck energy.

4. Choosing τ_0 differently would not change the structure of the theory, only the absolute scaling of β.

Thus, τ_0 is best understood as a natural calibration constant with physical motivation from quantum gravity considerations.

D.3.1 What If τ_0 Were Chosen Differently?

If τ_0 were replaced by some τ', then:

$$\beta' = \beta \cdot (\tau_0 / \tau')$$

All formulas, predictions, and interpretations would remain invariant up to a uniform scaling.

Therefore:

• τ_0 does not affect the *form* of the theory,

• but $\tau_0 = t\_P$ is the most natural *choice of units* for fundamental informational dynamics.

D.4 Clarifying the Role of the Perception Section (§9.6)

The perception-related discussion is *explicitly interpretive and speculative*. It is not part of the physical core of the theory.

Its purpose is to illustrate how a physics based on distinguishability and tick structure might interface with cognitive processes that also depend on distinguishability, integration, and information flow.

To avoid confusion, we explicitly state: The perception section does not alter, constrain, or justify any physical claims made in the main body of the paper.

It may be viewed as:

• supplementary context for interdisciplinary readers,

• an optional interpretive extension,

• or a standalone conceptual exploration.

Summary of Clarifications

• α-scaling fully explains gravitational redshift; β remains invariant.

• β_rest has a plausible physical pathway via Compton-scale internal oscillations.

• τ_0 = t_P is adopted as the natural calibration choice.

• Perception-related material is explicitly labelled speculative and non-core.

These clarifications strengthen the internal coherence, operational meaning, and interpretive boundaries of the Tick Framework as presented in the manuscript.

This document is part of the Void Energy-Regulated Space Framework (VERSF) and Bit Conservation and Balance (BCB) research programs. The tick-based reformulation provides a unified informational foundation for fundamental physics, revealing energy and spacetime geometry as emergent from discrete distinguishability dynamics.