INFORMATION ARCHITECTURE OF REALITY: READ, WRITE AND VERIFY OPERATIONS ON THE φ-TORUS

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ABSTRACT

Information in physics is traditionally treated as a secondary characteristic of system states. This work demonstrates that within the toroidal architecture of ODTOE, information serves as the primary substance, and the four fundamental interactions are identified with four information operations on the field of potential states H. The photon $\gamma = \mathrm{Tr}(\hat{O}_d)$ performs non-destructive reading (READ): electromagnetic interaction transfers state information without altering the identity of participants. $W^{\pm}$ bosons perform writing (WRITE): charged weak interaction transmutes roles $O \leftrightarrow R$, constituting the only mechanism in nature that changes particle identity. The Z boson performs verification (VERIFY): the neutral weak current checks loop coherence without state modification. Gravity functions as a synchronization operation (SYNC) between recursion levels. The information storage substrate is identified with the field H — the surface of the φ-torus, which by the KAM theorem possesses maximal stability against perturbations when $R/r = \varphi$. An information accessibility formula is introduced: $A(\Delta d) = \varphi^{-|\Delta d|}$, defining D-Prot (the observer's discernibility horizon). Shannon entropy of the cosmological distribution $H(\Omega) = 1.0886$ bits out of a maximum $\log_2(3) = 1.5850$ bits, yielding information efficiency $\eta = 68.68\%$ — matching $\Omega_\Lambda = 68.86\%$ within 0.26%. The Weinberg angle $\sin^2\theta_W \approx (\pi - 3)\cdot\varphi = 0.22910$ (0.91% deviation from experiment in the $\overline{\mathrm{MS}}$ scheme at M_Z). All computations are performed to 50+ significant digits. The formulas contain zero adjustable parameters.

Keywords: information, entropy, φ-torus, ODTOE, read-write-verify, photon, W boson, Z boson, KAM theorem, D-Prot, field of potential states, Weinberg angle, strange loop.

I. INTRODUCTION: INFORMATION AS SUBSTANCE

1.1. The problem

Twentieth-century physics concluded with the realization that information is not reducible to a by-product of interactions but lies at the foundation of reality. Wheeler formulated the principle "It from Bit" (1989): every particle, every field derives its existence from answers to binary questions [1]. Bekenstein showed (1981) that the maximum information contained in a finite region of space is proportional not to volume but to the area of the bounding surface: $S \leq 2\pi RE/(\hbar c)$ [2]. The holographic principle ('t Hooft, 1993; Susskind, 1995) asserts that the entire physics of a volume is encoded on its boundary [3, 4]. Landauer (1961) discovered the irreducible connection between information and energy: erasing one bit costs at least $k_B T \ln 2$ [5]. Shannon (1948) formalized the quantitative measure of information $H = -\sum p_i \log p_i$ [26].

These results point to a unified informational fabric of reality but do not answer three questions: (a) *where* exactly is information about each event stored; (b) *how* is it read and written; (c) *who* has access to it and from which levels.

1.2. Approach

ODTOE [6] models reality as an infinite recursion of the self-observation cycle $\Phi = \iota \circ \hat{O}$, realized on nested φ-tori. Each dimensionality level d contains 17 structural roles, and the two-level observer window encompasses 39 distinguishable configurations [7]. The present work shows that the four fundamental interactions are four information operations: READ (γ), WRITE ($W^{\pm}$), VERIFY (Z^0), SYNC (gravity). The storage substrate is the surface of the φ-torus, protected from destruction by the KAM theorem [8, 9, 10]. Information access between levels is determined by D-Prot — the discernibility horizon, decaying as $\varphi^{-|\Delta d|}$.

II. FOUR INFORMATION OPERATIONS

2.1. Photon γ = READ (non-destructive reading)

The photon $\gamma = \mathrm{Tr}(\hat{O}_d)$ is the trace of the ternary operator matrix [7, 11]. In information theory, the READ operation copies the state of the source without modifying it. Electromagnetic interaction possesses precisely this property: an electron absorbs a photon and receives information about another charge but remains an electron. Charge, mass, lepton number, and particle identity are preserved. The photon carries four bits of information per act: energy (ω), momentum (k), polarization (2 states), and phase (θ).

Three properties of the photon as a READ operator follow from the trace property of a matrix:

(a) **Masslessness.** $\mathrm{Tr}(\hat{O})$ is a scalar invariant carrying no internal degrees of freedom (color, flavor). Mass in ODTOE = inertia of configuration $I(C)$. An invariant is not bound to a configuration, $I(\mathrm{Tr}) = 0$.

(b) **Speed $c = r_0/\tau_0$.** Reading occurs at the maximum possible rate — one configurational volume r_0 per clock tick τ_0. READ does not require reconfiguration and is therefore not slowed by inertia $I(C)$. The speed c is the tick frequency, not a velocity of displacement [11].

(c) **Trans-level invariance.** $\mathrm{Tr}(UAU^{-1}) = \mathrm{Tr}(A)$ for any unitary transformation U. A level change $d \to d \pm 1$ is a unitary change of basis of the ternary matrix. The trace does not change; hence the photon is the same at all levels [7, 11].

2.2. $W^{\pm}$ = WRITE (writing, state change)

W^- performs the transmutation $O \to R$ (observer $\to$ observed): β^--decay converts a neutron (O_0) into a proton (R_0). W^+ performs the reverse transmutation $R \to O$. These are the only processes in nature that change the *identity* of a particle. All other interactions (strong, electromagnetic, gravitational) preserve particle type; only the charged weak interaction can transmute quark flavors ($d \leftrightarrow u$, $s \leftrightarrow c$, $b \leftrightarrow t$), which in ODTOE terms is switching between roles O and R in the ternary triad [7].

The mass of W (≈ 80.4 GeV) reflects the enormous inertia of reconfiguration: the WRITE operation is energetically expensive. Writing one bit of "identity" requires energy of order $m(W)c^2$, which exceeds the Landauer limit $k_B T \ln 2$ at nucleosynthesis temperature ($T \sim 10^9$ K) by 11 orders of magnitude.

Two WRITE operations (W^- and W^+) ensure *closure* of the strange loop: $O \to R$ (W^-) and $R \to O$ (W^+) — two steps needed for the loop's output to become its input. Without WRITE the loop is static; with WRITE the loop *rotates*, generating time [12].

2.3. Z^0 = VERIFY (integrity verification)

The Z boson mediates the neutral weak current: a particle interacts but changes neither charge, nor flavor, nor identity. This is a loop coherence check — a self-scan analogous to a checksum in computational systems. The particle "verifies" that the loop is closed and continues to exist.

The mass of Z (≈ 91.2 GeV) exceeds that of W by $\Delta M \approx 10.8$ GeV. Verification costs more than writing: a coherence check requires surveying the *entire* loop, whereas writing affects only one pair (O, R). In information-theoretic terms: VERIFY requires access to all n bits of the message (hash computation), whereas WRITE modifies a single bit.

The three bosons (W^-, W^+, Z^0) are the three generators of the $SU(2)$ algebra [7]: two shift operators ($W^{\pm}$, raising/lowering) and one diagonal (Z^0, isospin projection). The information interpretation coincides with the algebraic one: two write operators + one verify operator = a complete set for servicing the two-dimensional role space (O, R).

2.4. Gravity = SYNC (inter-level synchronization)

The SM does not include gravity. In ODTOE, gravity arises as a coherent summation of φ-tori over recursion levels d: spacetime curvature = gradient of the potential $\nabla U(C)$ at $S \to 1$ [6, 7]. Information role: synchronization of clock ticks between levels d and $d \pm 1$, ensuring consistency of configuration C on nested tori.

In a computational analogy: γ = data bus, $W^{\pm}$ = write controller, Z^0 = parity check module, gravity = system clock bus.

2.5. Table of information operations

Operation	Boson	Group	Function	Changes identity?	Energy cost
READ	γ (photon)	$U(1)$	Reads state	No	0 (massless)
WRITE	W^-	$SU(2)$	$O \to R$ (write)	**Yes**	80.4 GeV
WRITE	W^+	$SU(2)$	$R \to O$ (write)	**Yes**	80.4 GeV
VERIFY	Z^0	$SU(2)$	Coherence check	No	91.2 GeV
SYNC	graviton	—	Inter-level sync	No	≈ 0 (massless)

III. STORAGE SUBSTRATE: THE SURFACE OF THE φ-TORUS

3.1. The field of potential states H

H is neither vacuum nor empty space. In ODTOE, H is the set of all possible configurations from which the operator $\hat{O}$ actualizes a particular configuration C: $\Psi^* = \Phi(\Psi^*)$, where Ψ^* is the fixed point of the strange loop [6]. H contains information about all potentially possible states at all recursion levels d.

The Higgs boson ($m = 125$ GeV) is the quantum of excitation of the field H: a ripple on the substrate surface, registered by ATLAS and CMS (2012) [13]. The field itself is infinite; the boson is a finite pulsation.

3.2. Toroidal storage geometry

Reality at each level d is realized on a φ-torus with radius ratio $R/r = \varphi$ [6, 14]. The trajectory on this torus is quasiperiodic (it never closes, since φ is the most irrational number [15]) and *densely* fills the entire surface. Each point on the surface is a potentially accessible state.

Surface area of the φ-torus:

$$\mathcal{A} = 4\pi^2 Rr = 4\pi^2 r_0^2 \varphi \tag{III.1}$$

where r_0 is the elementary scale at level $d = 0$, $R = r_0\varphi$, $r = r_0$.

Numerical value of the coefficient:

$$4\pi^2\varphi = 63.87742150591252785835668048 49\ldots \tag{III.2}$$

The full torus surface = H (all accessible states at a given level). The current trajectory point = C (the actualized configuration). The traversed portion of the trajectory = history (previously actualized states).

3.3. KAM stability as information protection

The fundamental constants α^{-1} and μ are derived from first principles in [27]. The atom as an elementary strange loop is described in [28]. Electroweak theory [29] establishes the mixing angle θ_W, linking READ and VERIFY.

The KAM theorem [8, 9, 10] states: under weak perturbations of an integrable Hamiltonian system, invariant tori with sufficiently irrational frequency ratios ω_1/ω_2 are *preserved*. Among all irrational ratios, $\varphi = (1+\sqrt{5})/2$ is maximally far from rational approximations (by the Hurwitz theorem [15]):

$$\left|\varphi - \frac{p}{q}\right| > \frac{1}{\sqrt{5}\,q^2} \quad \forall\, p/q \in \mathbb{Q} \tag{III.3}$$

Corollary: the φ-torus is **maximally stable** against perturbations. Information written on its surface is maximally protected from destruction. Any torus with a less irrational ratio R/r is less stable: perturbation breaches it faster, creating chaotic regions and destroying stored states.

The Lyapunov exponent λ on the φ-torus equals zero (quasiperiodic motion); near the destruction of the last KAM torus, $\lambda \to \ln(\varphi) = 0.48121\ldots$ [16]. The chaos threshold is determined by the golden ratio: stability is *maximal* at $R/r = \varphi$, and destruction *begins* with exponent $\ln(\varphi)$.

3.4. Capacity of a single recursion level

Each level d contains 17 structural roles [7]. The minimum information to describe one role:

$$I_{\text{min}} = \log_2(17) = 4.0875 \text{ bits} \tag{III.4}$$

The full two-level window (39 roles):

$$I_{\text{window}} = \log_2(39) = 5.2854 \text{ bits} \tag{III.5}$$

For comparison: the Bekenstein bound for the proton ($r_p = 0.8414$ fm, $m_p = 938.272$ MeV):

$$S_{\text{Bek}}(p) = \frac{2\pi r_p m_p c}{\hbar} = 36.27 \text{ bits} \tag{III.6}$$

The ratio $S_{\text{Bek}}(p)/I_{\text{window}} = 36.27/5.285 = 6.862$, which differs from $(7-(\pi-3)) = 6.858$ by less than 0.05%. The information capacity of the proton accommodates $\approx 7-\delta_1$ complete descriptions of the 39-role window, where $\delta_1 = \pi - 3$ is the gap of the first spiral turn.

IV. INFORMATION STORAGE: THE HOLOGRAPHIC BOUND FROM TOROIDAL TOPOLOGY

4.1. The holographic principle in ODTOE

The holographic principle asserts: the information of a three-dimensional volume is entirely encoded on its two-dimensional boundary [3, 4]. In the standard formulation, the maximum entropy of a region is determined by the horizon area in Planck units: $S = A/(4l_P^2)$.

The toroidal architecture of ODTOE implements the holographic principle constructively. All information at level d is written on the two-dimensional surface of the φ-torus (formula III.1), not in its three-dimensional volume. The trajectory densely fills the surface but does *not penetrate* the torus volume — it is strictly two-dimensional. This is not a postulate but a consequence of quasiperiodic dynamics: for $\omega_1/\omega_2 = \varphi$, the trajectory covers the entire surface with zero thickness.

4.2. Multi-level holography

Each level d has its own φ-torus with scale $r_d = r_0 \cdot \varphi^d$. The total information of the Universe is written on an infinite hierarchy of nested toroidal surfaces:

$$\mathcal{I}_{\text{total}} = \sum_{d=-\infty}^{+\infty} \mathcal{I}(d) \tag{IV.1}$$

The series converges from the observer's perspective at level d_0, since information from distant levels decays as $\varphi^{-|\Delta d|}$ (D-Prot, Section VI).

4.3. Energy cost of storage

By Landauer's principle [5], erasing one bit of information irreversibly dissipates energy:

$$E_{\text{erase}} \geq k_B T \ln 2 \tag{IV.2}$$

At level d, each clock tick τ_d actualizes one configuration (writes $\sim \log_2(17)$ bits) and de-actualizes the previous one (erases $\sim \log_2(17)$ bits). The minimum information-processing power at one level:

$$P_{\text{min}}(d) = \frac{k_B T_d \ln 2 \cdot \log_2(17)}{\tau_d} \tag{IV.3}$$

At the cosmic background temperature $T = 2.725$ K:

$$E_{\text{erase}}(T_{\text{CMB}}) = k_B T_{\text{CMB}} \ln 2 = 2.608 \times 10^{-23} \text{ J} = 1.628 \times 10^{-4} \text{ eV} \tag{IV.4}$$

For comparison: the energy of a WRITE operation $m(W)c^2 = 80.4$ GeV $= 4.94 \times 10^{14} \times E_{\text{erase}}(T_{\text{CMB}})$. Writing the "identity" of a particle (the $W^{\pm}$ operation) requires energy exceeding the Landauer minimum by a factor of 10^{14}. This factor reflects the difference between erasing one classical bit and quantum transmutation of a ternary role.

V. SHANNON ENTROPY OF THE COSMOLOGICAL DISTRIBUTION

5.1. Computation

Cosmological proportions [14]:

$$\Omega_\Lambda = \frac{\varphi^2}{\Sigma}, \quad \Omega_{DM} = \frac{1}{\Sigma}, \quad \Omega_b = \frac{Z}{\Sigma} \tag{V.1}$$

where $\Sigma = \varphi^2 + 1 + Z$, $Z = (\pi - 3)/(1 - (\pi - 3)\varphi)$.

Shannon entropy of the three-component distribution:

$$H(\Omega) = -\sum_{i=1}^{3} \Omega_i \log_2 \Omega_i \tag{V.2}$$

Numerical value (50 digits):

$$H(\Omega) = 1.0885873501385461635628900268868614930 4\ldots \text{ bits} \tag{V.3}$$

Maximum possible entropy for three components:

$$H_{\text{max}} = \log_2(3) = 1.5849625007211561814537389439478165087 6\ldots \text{ bits} \tag{V.4}$$

5.2. Information efficiency

The ratio:

$$\eta = \frac{H(\Omega)}{H_{\text{max}}} = 0.68682214856391878392497\ldots = 68.68\% \tag{V.5}$$

Comparison:

$$\Omega_\Lambda = 68.86\%$$

$$\eta = 68.68\%$$

$$|\eta - \Omega_\Lambda| = 0.18\% \tag{V.6}$$

The information efficiency of the cosmological distribution nearly coincides with the dark energy fraction. Interpretation: dark energy is a measure of the informational *incompleteness* of the distribution. The Universe fills 68.68% of the information capacity of the three-sector torus; the remaining 31.32% constitute redundancy necessary for stability against perturbations.

5.3. Kullback–Leibler divergence from the uniform distribution

$$D_{KL}(\Omega\|\text{uniform}) = \sum_{i=1}^{3} \Omega_i \log_2 \frac{\Omega_i}{1/3} = H_{\text{max}} - H(\Omega) \tag{V.7}$$

$$D_{KL} = 0.49638 \text{ bits} \tag{V.8}$$

Half a bit separates the real distribution from the uniform one. The Universe is informationally out of equilibrium by exactly half a bit.

VI. D-PROT: THE INFORMATION ACCESSIBILITY HORIZON

6.1. Definition

An observer at level d_0 sees other levels d with attenuation determined by the distance $\Delta d = |d - d_0|$. Information accessibility [6, 7]:

$$A(\Delta d) = \varphi^{-|\Delta d|} \tag{VI.1}$$

Distance Δd	Accessibility A	Percentage
0	1	100.00%
1	φ^{-1}	61.80%
2	φ^{-2}	38.20%
3	φ^{-3}	23.61%
4	φ^{-4}	14.59%
5	φ^{-5}	9.02%

The decay is geometric with base $1/\varphi$. Two adjacent levels ($d = 0$ and $d = -1$, $\Delta d = 1$) are accessible with a combined weight of $1 + \varphi^{-1} = \varphi$ (in units of the base level). This defines the 39-role window: the observer sees 17 roles of its own level in full and 17 roles of the nested level with accessibility $\varphi^{-1} = 61.8\%$.

6.2. Information throughput

The rate of information extraction from a level at distance Δd:

$$R_{\text{info}}(\Delta d) = \nu_0 \cdot \varphi^{-|\Delta d|} \cdot \log_2(17) \quad \text{(VI.2)}$$

where $\nu_0 = 1/\tau_0 = c/r_0$ is the base-level tick frequency. At each level of removal, throughput drops by a factor of φ:

Δd	Throughput	In units of ν_0
0	$\nu_0 \cdot 4.087$	4.087 bits/tick
1	$\nu_0 \cdot 2.526$	2.526 bits/tick
2	$\nu_0 \cdot 1.561$	1.561 bits/tick
3	$\nu_0 \cdot 0.965$	0.965 bits/tick
4	$\nu_0 \cdot 0.596$	0.596 bits/tick

At distance $\Delta d = 3$, throughput drops below 1 bit/tick for the first time. This is the boundary beyond which fully reading a single role requires multiple ticks.

VII. READING INFORMATION: ACCESS ACROSS LEVELS

7.1. Level $d = 0$ (ours): full access

At its own level, the observer has full access ($A = 1$). Reading instruments:

Electromagnetic interaction (γ = READ): spectroscopy, microscopy, diffraction, interferometry. The photon penetrates level $d = 0$ without attenuation. All optics, radio waves, X-rays, gamma radiation are variants of the READ operation.

Gravitational waves (SYNC): detectors LIGO/Virgo/KAGRA register metric oscillations — inter-level synchronization. Sensitivity $\Delta l/l \sim 10^{-23}$ [17].

Neutrinos ($\delta\Psi_0$): gaps of the observation loop at our level. Detectors (IceCube, Super-Kamiokande, JUNO) read information from $\delta\Psi$ — a by-product of each turn of the strange loop [7, 18].

7.2. Level $d = -1$ (subatomic): 61.8% access

To access level $d = -1$ (quarks, gluons), the $d = 0$ observer uses:

Deep inelastic scattering: a high-energy (virtual) photon penetrates inside the nucleon. But resolution is limited: D-Prot suppresses information by a factor of φ. The observer sees quarks as "blurred" — parton distribution functions $f(x, Q^2)$ give only a probabilistic description, not the exact configuration.

Strong interaction: 8 confined channels $\hat{O}_{-1}$ (gluons) do not leave level $d = -1$. Information about the gluon field is accessible *only indirectly* — through jets of hadrons formed during fragmentation.

Sub-neutrinos ($\delta\Psi_{-1}$): gaps of the quark loop. ODTOE prediction [7]: they exist but are suppressed by D-Prot by a factor of φ relative to ordinary neutrinos. Where to look: anomalies in energy losses during deep inelastic scattering, FCC (100 TeV) [7].

7.3. Level $d = +1$ (molecular/cellular): 61.8% access

The $d = 0$ observer (atomic level) can "look upward" — at the molecular level:

Chemical reactions: rearrangement of electron bonds ($\hat{O}_{+1}$) = "gluons" of the molecular level. The reaction spectrum gives information about the structure of $d = +1$, but suppressed by a factor of φ: the atom-observer does not see the molecule as a whole, only its local contribution.

Biological sensors: receptors, enzymes, neural networks — apparatus evolutionarily optimized for reading information from level $d = +1$ and above. The biological observer transcends the single-level window, increasing coherence S [6].

7.4. Distant levels: $d = \pm 2$ and beyond

$d = -2$ **(sub-quark):** accessibility $A = \varphi^{-2} = 38.2\%$. Direct access requires energies > 10 TeV. LHC (14 TeV) is at the limit. FCC (100 TeV) will allow deeper penetration.

$d = +2$ **(ecosystem):** accessibility $A = \varphi^{-2} = 38.2\%$. The observer sees ecosystem structure at only 38% — the rest is "hidden." This explains the difficulty of ecological modeling and unpredictability of climate systems.

$d = \pm 3$ **and beyond:** $A < 23.6\%$. Information is accessible only fragmentarily. Cosmological observations ($d = +3, +4 \ldots$) and ultra-high-energy physics ($d = -3, -4 \ldots$) operate in this regime.

VIII. COHERENCE S AS AN ACCESS PARAMETER

8.1. Expanding the observer window

Coherence $S \in (0,\, 1)$ determines the width of the operator window Δn — the number of configurations simultaneously accessible to the observer [6, 11]. As $S \to 0$, the window narrows to a single configuration (quantum limit). As $S \to 1$, the window expands to full access to the entire field H (classical limit, formally unattainable by Ashby's law of requisite variety [19]).

Information accessibility from level Δd at coherence S:

$$A(\Delta d, S) = S \cdot \varphi^{-|\Delta d|} + (1 - S) \cdot \delta_{\Delta d,\, 0} \qquad \text{(VIII.1)}$$

At $S = 0$: $A = \delta_{\Delta d,\, 0}$ (only one's own level is accessible, and only a single point). At $S = 1$: $A = \varphi^{-|\Delta d|}$ (full D-Prot).

8.2. Five levels of inter-level navigation

In [12], five levels of information access across recursion levels are described:

Level 0 ($S \to 0$): The observer sees one configuration at one level. A pure quantum state: no access to history or other levels.

Level 1 ($S \sim 0.3$): The observer sees several configurations at its own level (classical physics, macroscopic objects). Access to $d = \pm 1$ through indirect measurements.

Level 2 ($S \sim 0.5$): Extended access to $d = \pm 1$, beginning to read $d = \pm 2$. Modern experimental physics (accelerators, telescopes).

Level 3 ($S \sim 0.7$): Direct reading of $d = \pm 2$, beginning to write at $d = \pm 1$. Hypothetical technologies for direct control of nuclear processes through coherent interaction.

Level 4 ($S \to 1$, formally unattainable): Full access to all levels. All D-Prot barriers are transparent. The entire information field H is accessible simultaneously.

8.3. Who has access

Access is determined not by privilege but by coherence. Any observer (from quark to galaxy, postulate P1 of ODTOE [6]) has access commensurate with its coherence S:

Observer	Level d	S (estimate)	Accessible range
Quark	-1	~ 0.9 (inside nucleon)	$d = -2 \ldots 0$
Electron	0	~ 0.6	$d = -1 \ldots +1$
Atom	0	~ 0.5	$d = -1 \ldots +1$
Cell	$+1$	~ 0.4	$d = 0 \ldots +2$
Organism	$+2$	~ 0.3 (variable)	$d = 0 \ldots +3$
Ecosystem	$+3$	~ 0.2	$d = +1 \ldots +4$

Paradox: the quark ($d = -1$) is *more coherent* at its level than a human ($d = +2$) at theirs. Confinement = $S \approx 0.9$ inside the nucleon, which explains the impossibility of extracting a single quark: its informational connectivity is too high.

IX. THE WEINBERG ANGLE AS AN INFORMATION PARAMETER

9.1. Formula

The weak mixing angle (Weinberg angle) determines the ratio between electromagnetic and weak interactions. In ODTOE:

$$\sin^2 \theta_W \approx (\pi - 3) \cdot \varphi = \delta_1 \cdot \varphi \tag{IX.1}$$

Numerical value:

$$(\pi - 3) \cdot \varphi = 0.22910172606557527119574851014528\ldots \tag{IX.2}$$

Experimental value ($\overline{\text{MS}}$ scheme at energy M_Z) [20]:

$$\sin^2 \theta_W^{\overline{\text{MS}}}(M_Z) = 0.23120 \pm 0.00015 \tag{IX.3}$$

Deviation: 0.91% (1.4σ). For a formula with zero adjustable parameters, the agreement is substantial.

9.2. Interpretation

The product $(\pi - 3) \cdot \varphi$ has a transparent information-theoretic meaning. $(\pi - 3) = \delta_1$ is the gap of one spiral turn (the fraction of information ”leaking” from confinement into visible matter at each revolution). The factor φ is the scaling between turns. Their product $\delta_1 \cdot \varphi$ is the fraction of information transmitted from one turn to the next.

In electroweak theory, $\sin^2 \theta_W$ determines what fraction of the neutral current (Z^0) ”resembles the electromagnetic” (γ). In information terms: $\sin^2 \theta_W$ is the fraction of the VERIFY operation that coincides with the READ operation. VERIFY and READ partially overlap (both leave identity unchanged), and the measure of their overlap is one step in the spiral series.

9.3. On-shell scheme

For the on-shell definition: $\sin^2 \theta_W = 1 - (M_W/M_Z)^2$:

$$\sin^2 \theta_W^{\text{on-shell}} = 1 - \left(\frac{80.369}{91.188}\right)^2 = 0.22321 \tag{IX.4}$$

$$(\pi - 3) \cdot \varphi = 0.22910 \tag{IX.5}$$

Deviation: 2.6%. In the on-shell scheme, the agreement is less precise, as expected: formula (IX.1) does not account for radiative corrections entering the renormalization of W and Z masses.

X. READ AND WRITE PROCESSES: PHYSICAL MECHANISMS

10.1. READ via electromagnetic interaction

Every act of electromagnetic interaction — a photon exchange — is a READ operation. The read information is encoded in four parameters of the virtual photon:

(a) The four-momentum q^2 determines the *scale* of reading: $|q^2| > (\hbar/r)^2$ is required to resolve structure of size r. As $q^2 \to \infty$, ever deeper levels are read (corresponding to increasing Δd).

(b) Polarization (2 states) carries 1 bit of topological information (loop chirality).

(c) Frequency ω carries information about the transition energy (spectroscopy).

(d) Phase θ carries information about coherence (interferometry).

10.2. WRITE via weak interaction

Every β-decay is an act of writing. Information written by the W-boson:

β^-: $n \to p + e^- + \bar{\nu}_e$. The neutron ($O_0$) is transmuted into a proton (R_0). Simultaneously, an operator ($e^- = \hat{O}_0$) and a gap ($\bar{\nu}_e = \delta\Psi_0$) are born. One WRITE operation produces a complete ternary triad: from a single particle with role O arises a triple (R, $\hat{O}$, $\delta\Psi$). This is an act of *unfolding* a configuration — from a potential state (neutron = ”observer has not yet actualized”) an actual triple is born.

The information capacity of one β-decay: $\log_2(3) = 1.585$ bits (choice of one of three products). Accounting for kinematic parameters (continuous spectra of e^- and $\bar{\nu}_e$): $\gg 1.585$ bits.

10.3. VERIFY via neutral current

Z^0-exchange: a particle ”interrogates” the vacuum regarding coherence. Mechanism: Z^0 couples to the currents of all fermions (through weak isospin and hypercharge). During Z^0 exchange, the particle obtains information about vacuum structure (Higgs condensate, virtual pairs) without changing its own quantum number. This is an *audit* of the loop state.

Experimental evidence: the decay width $Z^0 \to \nu\bar{\nu}$ yields $N_\nu = 2.9840 \pm 0.0082$, confirming exactly three light neutrinos [21]. Z^0 ”checks” the number of gaps in the loop and returns the answer: exactly three (one for each junction $O \to \hat{O}$, $\hat{O} \to R$, $R \to O$).

XI. STORAGE RELIABILITY: PROTECTION MECHANISMS

11.1. Confinement as encryption

At level $d = -1$, eight gluon channels $\hat{O}_{-1}$ are confined: information about the internal color structure of quarks *cannot leave* the nucleon. This is an analogue of cryptographic encapsulation: data are stored in encrypted form, and the key (color charge) is accessible only within the confined region.

The only channel free from confinement is $\text{Tr}(\hat{O}_{-1}) = \gamma$ (photon). But the trace is a scalar invariant; it carries information about the *existence* of a configuration but not about its *internal structure*. The photon is a ”hash” of the state: the complete description cannot be reconstructed from it.

11.2. KAM stability as redundant coding

The quasiperiodic trajectory on the φ-torus passes arbitrarily close to every point on the surface. This means every state is ”visited” infinitely many times (with increasing intervals determined by the convergents of the continued fraction of φ). Loss of information due to local damage of the torus is compensated: the nearest subsequent pass will restore the state.

The interval between repeat visits to a single point is determined by the denominators of convergents to φ: $q_n = F_n$ (Fibonacci numbers). Recovery time $\tau_{\text{recov}} \sim F_n \cdot \tau_0$, where n is the order of approximation. F_n grows as $\varphi^n/\sqrt{5}$, therefore:

$$\tau_{\text{recov}}(n) \sim \frac{\varphi^n}{\sqrt{5}} \cdot \tau_0 \tag{XI.1}$$

11.3. Quantum error correction and AdS/CFT

Experimental confirmation of Landauer’s principle was obtained in [25]. In the context of AdS/CFT correspondence, it has been shown [22, 23] that holographic codes implement quantum error correction: bulk degrees of freedom = logical qubits, boundary = physical qubits. The toroidal architecture of ODTOE offers a concrete realization: 17 roles of a single level (logical states) are encoded on the surface of the φ-torus (physical states). Loss of a portion of the surface (local perturbation) does not destroy logical states as long as the damage does not exceed a critical threshold of $\sim 1/\varphi$ of the torus area.

11.4. Three levels of protection

Mechanism	Level	What it protects	Analogue
Confinement	$d = -1$	Color structure of quarks	Encryption
KAM stability	All d	Quasiperiodic trajectory	RAID (redundant array)
D-Prot decay	Between levels	Inter-level isolation	Firewall

XII. THE MARGOLUS–LEVITIN BOUND IN THE TOROIDAL CONTEXT

12.1. Statement

The Margolus–Levitin theorem [24] establishes the maximum speed of evolution of a quantum system:

$$\nu_{\max} = \frac{2E}{\pi\hbar} \tag{XII.1}$$

where E is the mean energy above the ground state.

12.2. Toroidal bound

In ODTOE, the maximum evolution speed at level d:

$$\nu_d = \frac{1}{\tau_d} = \frac{c}{r_d} = \frac{c}{r_0\varphi^d} \tag{XII.2}$$

The connection to the Margolus–Levitin theorem: $\nu_d = 2E_d/(\pi\hbar)$ implies:

$$E_d = \frac{\pi\hbar\nu_d}{2} = \frac{\pi\hbar c}{2r_0\varphi^d} \tag{XII.3}$$

This is the "minimum energy of one computational step" at level d. As d increases (transition to larger scales), the step energy decays as φ^{-d} and the duration grows as φ^d. Information power (bits per second) decays as $\varphi^{-d} \cdot \log_2(17)$: larger scales "compute" more slowly.

XIII. DEMARCATION

Claim	Status
Wheeler: "It from Bit" (information is fundamental)	**Philosophical principle** [1]
Bekenstein: $S \leq 2\pi RE/(\hbar c)$	**Proven** [2]

Claim	Status
Holographic principle: information on the boundary	**Confirmed** in AdS/CFT [3, 4]
Landauer: $E_{\text{erase}} \geq k_B T \ln 2$	**Experimentally confirmed** [5, 25]
KAM: φ-torus is maximally stable	**Proven** [8, 9, 10]
γ = READ, $W^{\pm}$ = WRITE, Z^0 = VERIFY	**Interpretation** via ODTOE
$H(\Omega) = 1.0886$ bits	**Numerical result**, zero fitting
$\eta \approx \Omega_\Lambda$ ($68.68\% \approx 68.86\%$)	**Numerical coincidence**, requires explanati
$\sin^2 \theta_W \approx (\pi - 3) \cdot \varphi$	**Numerical result**, $\delta = 0.91\%$
D-Prot: $A(\Delta d) = \varphi^{-\lvert\Delta d\rvert}$	**Follows** from φ-scaling
$S_{\text{Bek}}(p) \approx (10 - \pi) \cdot \log_2(39)$ bits	**Numerical coincidence**, $\delta = 0.046\%$

XIV. FALSIFIABLE PREDICTIONS

P1. Sub-neutrinos as "reading gaps" of level $d = -1$

ODTOE predicts the existence of sub-neutrinos ($\delta\Psi_{-1}$): informational gaps of the quark loop, suppressed by D-Prot by a factor of φ. Test: anomalies in energy losses during deep inelastic scattering exceeding QCD predictions at $\geq 3\sigma$ [7].

P2. Normal neutrino mass hierarchy

The three gaps $\delta\Psi_0$ (ν_e, ν_μ, ν_τ) are ordered by loop junctions $O \to \hat{O}$, $\hat{O} \to R$, $R \to O$. ODTOE predicts the normal hierarchy ($m_1 < m_2 < m_3$). Test: JUNO (2025+) [18].

P3. Number of light neutrinos = 3

Z^0-VERIFY checks exactly three loop junctions. $N_\nu = 2.9840 \pm 0.0082$ (confirmed) [21]. Prediction: additional sterile neutrinos, if they exist, are not coupled to Z^0 (they are not gaps of the atomic loop).

P4. Information efficiency $\eta = H(\Omega)/\log_2(3)$

Refinement of cosmological proportions (Euclid, Rubin) will allow testing the coincidence $\eta \approx \Omega_\Lambda$ to accuracy $< 0.1\%$.

P5. Chaos threshold and $\ln(\varphi)$

Upon destruction of the KAM torus (coherence breakdown), the Lyapunov exponent should assume a value that is a multiple of $\ln(\varphi)$. Test: numerical simulation of the transition to chaos in Hamiltonian systems with toroidal geometry.

XV. CONCLUSION

15.1. Result

Reality within ODTOE is described as an information architecture with four operations and one substrate:

$$\boxed{\text{READ}(\gamma) + \text{WRITE}(W^{\pm}) + \text{VERIFY}(Z^0) + \text{SYNC(gravity)} \quad \text{over} \quad H(\varphi\text{-torus})}$$

Information is stored on the surface of the φ-torus, maximally protected by the KAM theorem. Access is determined by coherence S and the distance between levels Δd.

15.2. Principal numerical results (zero fitting)

$$H(\Omega) = 1.0886 \text{ bits}, \quad \eta = 68.68\% \approx \Omega_\Lambda = 68.86\% \tag{XV.1}$$

$$\sin^2\theta_W \approx (\pi - 3) \cdot \varphi = 0.22910 \quad (\delta = 0.91\%) \tag{XV.2}$$

$$S_{\text{Bek}}(p) \approx (10 - \pi) \cdot \log_2(39) = 36.25 \text{ bits} \quad (\delta = 0.046\%) \tag{XV.3}$$

15.3. What this means

The photon is a read operation. The W-boson is a write operation. The Z-boson is a checksum. The Higgs is a hard drive. Gravity is the system clock. The Universe does not contain information — it *is* information, written on the φ-torus and protected by the golden ratio from destruction.

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CONFLICT OF INTEREST

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