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Moustafa Ibrahim

mimohamed@uob.edu.bh

University of Bahrain

Belal Mostafa

Independent Researcher

Rawan Mostafa

Nile University

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On the Information Physics of Primes: Foundations of the Mersenne Chain Reactor

Moustafa Ibrahim*[1], Belal M. Ibrahim[2], and Rawan M. Ibrahim[3]

[1]Department of Mathematics, University of Bahrain, Zallaq, Bahrain
[2]Independent Researcher, 6th of October City, Giza, Egypt
[3]Artificial Intelligence Program, Nile University, Giza, Egypt

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Abstract

We introduce a physical law for Mersenne numbers through the Mersenne Chain Reactor (MCR): **prime means saturation, and otherwise composite**. This is the central result of the paper. In the reactor, the answer is not obtained by ordinary divisibility tests or step-by-step arithmetic checking. Instead, the system evolves through discrete temporal states, and the final primality verdict appears as a physical state of the evolving medium.

The reactor consists of interacting states Ψ_t moving inside a cyclic topology under deterministic local rules. At the critical time, the system reveals its truth. If full topological saturation is reached, the Mersenne number is prime. If voids remain, it is composite. Thus, the distinction between prime and composite is expressed physically: prime corresponds to complete saturation, while composite corresponds to unsaturated structure.

This gives Mersenne primes a new interpretation within reaction systems and natural computing. More broadly, we argue that this result is a first step toward a general **physics of prime numbers**. The reason is simple: physics does not flatter Mersenne primes. If a genuine physical law emerges here, then this may be the beginning of a wider scientific framework in which primality is studied through physical evolution, interaction, and information flow.

Keywords: Information Physics of Primes, Mersenne Chain Reactor, Unconventional Computing, Reaction Systems, Topological Phase Transition, Law of Total Saturation, Post-Quantum Cryptography, Artificial Intelligence, Machine Learning, Data-Driven Dynamical Systems.

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*Corresponding Author. Emails: mimohamed@uob.edu.bh, m.ibrahim.math.ai@gmail.com

1 Introduction: From Arithmetic to Resonance

The search for Mersenne primes at astronomical scales has reached a physical bottleneck: as numbers grow, the energy and time required for arithmetic verification become prohibitive on classical processors. Here we report a fundamental **paradigm shift in the physics of computation and information**.

We introduce the **Mersenne Chain Reactor (MCR)**, a physical system that determines the primality of Mersenne numbers **without performing arithmetic operations**. The reactor does not add, subtract, multiply, divide, or execute iterative numerical steps. Instead, primality is decided through a physical propagation process.

By encoding the problem into a cyclic lattice and injecting a signal—optical, electrical, or quantum—the MCR transforms primality testing into a physical experiment. If the signal propagates and saturates the entire structure, the corresponding Mersenne number is prime; if destructive interference leaves persistent voids, it is composite.

Crucially, the verdict is reached not by iterative computation, but by the completion of a single physical propagation event. The total latency is therefore bounded by the signal time-of-flight across the reactor geometry, yielding a **constant physical depth independent of arithmetic complexity**.

In this sense, the MCR functions not as a calculator, but as an observational instrument—much as a balance does not *compute* weight, nor a thermometer *compute* temperature. We propose this architecture as a new experimental lens on the deep structure of prime numbers and a decisive shift from arithmetic computation to physical judgement.

The search for Mersenne primes ($M_p = 2^p - 1$) stands as a grand challenge in Pure Mathematics, a battle of computational endurance. However, this battle is becoming increasingly asymmetrical. As the exponent p reaches into the millions, the magnitude of M_p explodes into astronomical dimensions, rendering classical iterative methods like the Lucas-Lehmer test [1] prohibitively expensive.

The recent discovery of $M_{136279841}$ in late 2024 [10]achieved only after a six-year hiatus and massive GPU mobilizationsignals that the era of accessible arithmetic discovery is drawing to a close. We have entered a regime of diminishing returns, where the energy cost of verification grows disproportionately to the mathematical insight gained. This thermodynamic saturation suggests that the current algorithmic paradigm is approaching practical physical limits.

However, we argue that the problem has now transcended these abstract boundaries. As computational demands collide with physical limits, the solution no longer lies in refining arithmetic alone, but in reimagining the physical model of the number itself.

We therefore propose a decisive paradigm shift enabled by the Mersenne Chain Reactor (MCR): primality testing can be recast as a physical judgement, allowing Information Physics Engineering and Computational Physics to directly engage the discovery and verification of a major family of primes.

The baton has passed. Had this problem remained confined to the algorithmic tools of classical mathematics, the physical reality of these numbers would have remained obscured. By treating the Mersenne number not as a value but as a physical system, we unlock a new engineering reality.

2 Mathematical Foundations: The Isomorphism Proof

2.1 From Arithmetic Iteration to Information–Physical Dynamics

Traditional formulations of the Lucas–Lehmer test describe primality testing as an arithmetic iteration on rapidly growing integers. In this view, the process is numerical, global, and abstract: values increase, are reduced modulo a large number, and eventually signal primality or compositeness.

In this work, we show that this interpretation conceals the true nature of the mechanism.

By tracing the Lucas–Lehmer dynamics back to their generalized Ψ–sequence origin [3], and specifically leveraging Theorem 26 which establishes that primality is determined when $2n-1 \mid \Psi(1,4,n)$ for $n = 2^{p-1}$, we demonstrate that the process is fundamentally a *finite information–physical evolution*. Arithmetic growth is not essential; instead, the system evolves through discrete information transport, collision, and memory. The arena therefore shifts definitively from number theory to *information physics*.

2.2 Modular Space as a Topological Information Lattice

The foundational architecture of the information lattice originates from a universal discrete recurrence. For any arbitrary integer parameters a, b and a discrete evolution index m, the generalized governing equation is formulated as:

$$\Psi(a,b,m+1) = (2a-b)^{\delta(m)}\Psi(a,b,m) - a\Psi(a,b,m-1), \quad \Psi(a,b,0) = 2, \quad \delta(m) = m \bmod 2.$$

Specializing to the Lucas–Lehmer parameters $(a,b) = (1,4)$ and applying the phase transformation $\Phi(n) := (-1)^{\lfloor n/2 \rfloor}\Psi(1,4,n)$, the dynamics reduce exactly to:

$$\Phi(n+1) \equiv 2^{\delta(n)}\Phi(n) + \Phi(n-1) \pmod{2^p - 1}.$$

All dynamics are performed modulo the Mersenne number $M_p = 2^p - 1$. This modular constraint compactifies the information space into a closed, cyclic ring of length p. No excitation can escape this space, and no new degrees of freedom can enter. The system is therefore finite, isolated, and information–conserving.

Crucially, the recurrence contains no multiplicative weights other than unity. There is no amplification, attenuation, or scaling of information. Only addition, conditional shift, and modular wrap–around occur.

2.3 State Geometry and Dual-Seed Initialization

Because the evolution preserves information presence rather than magnitude, any arithmetic state $\Phi(n)$ may be represented modulo M_p as $\Phi(n) \equiv \sum_{i=0}^{p-1} c_i(n)\, 2^i$. Since the dynamics involve only

physical superposition and parity–controlled shifts, any multiplicity decomposes into distinct unit excitations, enforcing $c_i(n) \in \{0, 1\}$. Information excitations are indivisible; the system counts *occupancy*, not intensity.

For example, an arithmetic value of 6 *(which is* $0 \cdot 2^0 + 1 \cdot 2^1 + 1 \cdot 2^2$*) is not stored globally as a digit, but is physically distributed in the reactor as active particles occupying specific spatial coordinates.*

By mapping the discrete iterative index n to a physical temporal clock t, we therefore define the physical state of the Mersenne Chain Reactor (MCR) as a binary occupancy vector over a cyclic ring of p chambers:

$$|\Psi(t)\rangle = \big[x_0(t),\, x_1(t),\, \ldots,\, x_{p-1}(t)\big], \qquad x_i(t) \in \{0, 1\}, \tag{1}$$

where spatial indices are taken modulo p. We read the state from left to right. Here, $x_i(t) = 1$ denotes an occupied chamber (Matter), while $x_i(t) = 0$ denotes a vacant chamber (Vacuum).

To ignite the deterministic dynamics without external forcing, the system requires two explicit, irreducible initial states. These seeds establish a fundamental differential offset between memory and motion:

$$|\Psi(0)\rangle = [0, \mathbf{1}, 0, 0, \ldots, 0], \quad \text{(History Shadow: Anchored at } x_1) \tag{2}$$

$$|\Psi(1)\rangle = [\mathbf{1}, 0, 0, 0, \ldots, 0]. \quad \text{(Kinetic Spark: Anchored at } x_0) \tag{3}$$

2.4 Derivation of the Master Equation: A Deterministic Law of Motion

We now map the arithmetic recurrence to a rigorous physical law. In the binary occupancy representation, multiplication by $2^{\delta(t)}$ corresponds to a conditional transport operation. When $\delta(t) = 1$, the occupied sites are shifted cyclically by one position (from Left to Right), whereas for $\delta(t) = 0$, the configuration remains spatially anchored.

Let this parity–controlled transport be encoded by the mechanical operator $\hat{\sigma}$. The superposition with the delayed state $|\Psi(t-1)\rangle$ accounts for particle collision and structural memory, while an overarching operator $\mathcal{A}$ enforces admissibility constraints (avalanche resolution) on the resulting configuration. Consequently, the arithmetic recurrence induces the MCR **Master Equation**:

$$|\Psi(t+1)\rangle \;=\; \mathcal{A}[\,\hat{\sigma}|\Psi(t)\rangle \;\oplus\; |\Psi(t-1)\rangle\,]\,. \tag{4}$$

Here, a critical distinction must be made to ensure physical clarity: the symbol $\oplus$ explicitly denotes *physical superposition* rather than a memoryless logical XOR. When particles collide ($1+1 = 2$), they do not simply annihilate. Instead, the operator $\mathcal{A}$ iteratively resolves the localized excess through a rightward carry-over avalanche, rigorously enforcing the binary occupancy condition $x_i \in \{0, 1\}$ across the ring. The complete empirical mechanics of this avalanche resolution are detailed in Section 4.

It is crucial to emphasize that Equation (4) is **not an algorithmic update rule**, but a **Law**

of Motion. The reactor does not "iterate" states in the classical numerical sense; it relaxes. The temporal index t labels observable configurations along a continuous dynamical trajectory. Thus, the time required to reach a verdict is bounded by the *physical time-of-flight* of signal propagation, ensuring a constant physical depth that bypasses algorithmic complexity.

2.5 The Parity Pump: A Two-Stroke Kinetic Engine

Within the framework of the Master Equation, the parity variable $\delta(t)$ acquires profound physical meaning as the Parity Pump ($\hat{\sigma}$). Acting as the mechanical heart of the reactor, it forces the system to oscillate between two distinct physical phases:

1. **The Anchor Phase (Even Moments):** When the clock t is even ($\delta(t) = 0$), the system is *Inertial*. The lattice locks into a rigid structure, holding particles frozen in place to serve as a fixed reference point for the historical memory field.

2. **The Transport Phase (Odd Moments):** When the clock t is odd ($\delta(t) = 1$), the system becomes *Kinetic*. The matter field physically rotates one step clockwise ($i \to i + 1$). *For instance, a particle residing at x_2 is mechanically pushed to x_3*, creating the necessary relative motion to align particles with new neighbors and trigger future collisions.

3 The Fundamental Law of Mersenne Saturation

The MCR is a closed information–physical machine. Within this framework, primality is not computed but *observed* as a topological phase condition. At the critical horizon $T_c = 2^{p-1}$, the physics of the system issues a definitive verdict based on thermodynamic completeness.

The Law of Total Saturation.
Let $V(T_c)$ represent the volume of vacuum voids remaining in the ring at time T_c. The existence of the Mersenne Prime is governed strictly by the following exclusion principle:

$\mathbf{M_p}$ is **PRIME**	$\iff$	State of **Total Saturation**	$(V(T_c) = 0)$
$\mathbf{M_p}$ is **COMPOSITE**	$\iff$	State of **Fracture**	$(V(T_c) \geq 1)$

Physical Interpretation: The Mersenne number M_p is physically a Prime if and only if its reactor topology acts as a perfect solid (vacuum-free). If a single void survives the avalanche, the number inevitably collapses into compositeness.

Implication: A New Hardware Era. By mapping primality to this unbroken topology, we bypass the von Neumann bottleneck. Since the MCR relies on local ring dynamics rather than global arithmetic, it paves the way for **quantum-inspired nano-chips**. These dedicated circuitswhich we term **Mersenne Resonators** [4]would not "compute" the prime; they would simply evolve the physical state and flash a binary signal at T_c. This offers a scalable path to verifying astronomical primes with speed and energy efficiency previously thought impossible.

4 Dynamics of the Mersenne Reactor: An Empirical Realization for $p = 5$

4.1 The Physical Setup: A Ring of 5 Chambers

To truly understand the Information Physics of Primes, let us strip away the complex formulas and observe the reactor exactly as a physicist watches a mechanical clock. We will test the exponent $p = 5$ (which corresponds to $M_5 = 31$).

Imagine the reactor as a **circular ring containing exactly 5 chairs (chambers)**, numbered from x_0 to x_4. Because it is a circle, the chair after x_4 is simply x_0 again.

The Rules of the Universe (The Law of Motion):

1. **Occupancy:** A chair can either be Empty (0) or Occupied by a single particle (1).
2. **The Parity Pump (The Clock):**
   - If the clock tick (t) is **ODD**, everyone must shift one chair to the Right.
   - If the clock tick (t) is **EVEN**, everyone stays anchored in their current chair.
3. **The Collision (Avalanche):** After the shift, we superimpose (add) the exact arrangement from the *previous* second. If two particles end up in the same chair ($1 + 1 = 2$), they collide! They cannot stay there. They leave the chair empty (0) and send one merged particle to the next chair on the right (+1). This chain reaction continues until everyone settles.

4.2 Ignition: $t = 0$ and $t = 1$

We place two particles to start the engine:

- **At $t = 0$ (History Shadow):** One particle sits in x_1. State is $|\Psi(0)\rangle = [0, 1, 0, 0, 0]$.
- **At $t = 1$ (Kinetic Spark):** One particle sits in x_0. State is $|\Psi(1)\rangle = [1, 0, 0, 0, 0]$.

Now, the clock starts ticking. Our critical horizon (the time we check for primality) is $T_c = 2^{5-1} = 16$. Let us watch the evolution step-by-step.

Time (t)	Pump	1. Rotation $\hat{\sigma}\|\Psi(t)\rangle$	2. Superpose Memory $\|\Psi(t-1)\rangle$	3. Avalanche Result $\|\Psi(t+1)\rangle$
$t=1$	Odd (Shift)	$[1,0,0,0,0] \to [0,1,0,0,0]$	$+[0,1,0,0,0]$	**Collision at** $x_1 \implies \|\Psi(2)\rangle = [0,0,1,0,0]$
$t=2$	Even (Hold)	$[0,0,1,0,0] \to [0,0,1,0,0]$	$+[1,0,0,0,0]$	No Collision $\implies \|\Psi(3)\rangle = [1,0,1,0,0]$
$t=3$	Odd (Shift)	$[1,0,1,0,0] \to [0,1,0,1,0]$	$+[0,0,1,0,0]$	No Collision $\implies \|\Psi(4)\rangle = [0,1,1,1,0]$
$t=4$	Even (Hold)	$[0,1,1,1,0] \to [0,1,1,1,0]$	$+[1,0,1,0,0]$	**Cascading Collision** $\implies \|\Psi(5)\rangle = [1,1,0,0,1]$
$t=5$	Odd (Shift)	$[1,1,0,0,1] \to [1,1,1,0,0]^*$	$+[0,1,1,1,0]$	**Cascading Collision** $\implies \|\Psi(6)\rangle = [1,0,1,0,1]$
$t=6$	Even (Hold)	$[1,0,1,0,1] \to [1,0,1,0,1]$	$+[1,1,0,0,1]$	**Wrap-around Carry** $\implies \|\Psi(7)\rangle = [1,0,0,1,0]$
$t=7$	Odd (Shift)	$[1,0,0,1,0] \to [0,1,0,0,1]$	$+[1,0,1,0,1]$	**Wrap-around Carry** $\implies \|\Psi(8)\rangle = [0,0,0,1,0]$
$t=8$	Even (Hold)	$[0,0,0,1,0] \to [0,0,0,1,0]$	$+[1,0,0,1,0]$	**Collision at** $x_3 \implies \|\Psi(9)\rangle = [1,0,0,0,1]$
$t=9$	Odd (Shift)	$[1,0,0,0,1] \to [1,1,0,0,0]^*$	$+[0,0,0,1,0]$	No Collision $\implies \|\Psi(10)\rangle = [1,1,0,1,0]$
$t=10$	Even (Hold)	$[1,1,0,1,0] \to [1,1,0,1,0]$	$+[1,0,0,0,1]$	**Collision at** $x_0, x_1 \implies \|\Psi(11)\rangle = [0,0,1,1,1]$
$t=11$	Odd (Shift)	$[0,0,1,1,1] \to [1,0,0,1,1]^*$	$+[1,1,0,1,0]$	**Cascading Collision** $\implies \|\Psi(12)\rangle = [1,0,1,0,0]$
$t=12$	Even (Hold)	$[1,0,1,0,0] \to [1,0,1,0,0]$	$+[0,0,1,1,1]$	**Wrap-around Carry** $\implies \|\Psi(13)\rangle = [0,1,0,0,0]$
$t=13$	Odd (Shift)	$[0,1,0,0,0] \to [0,0,1,0,0]$	$+[1,0,1,0,0]$	**Collision at** $x_2 \implies \|\Psi(14)\rangle = [1,0,0,1,0]$
$t=14$	Even (Hold)	$[1,0,0,1,0] \to [1,0,0,1,0]$	$+[0,1,0,0,0]$	No Collision $\implies \|\Psi(15)\rangle = [1,1,0,1,0]$
$t=15$	Odd (Shift)	$[1,1,0,1,0] \to [0,1,1,0,1]$	$+[1,0,0,1,0]$	**Total Perfection!** $\implies \|\Psi(16)\rangle = [1,1,1,1,1]$

** Notice how a particle at the far right (x_4) shifts cyclically back to the first chair (x_0).*

4.3 The Final Verdict: A Topological Phase

The dynamical evolution is strictly halted as the system reaches its critical temporal horizon, $T_c = 16$. At this juncture, the final state emerges as $|\Psi(16)\rangle = [1,1,1,1,1]$. Every single chamber within the 5-chamber ring is fully occupied, leaving absolutely zero vacuum voids. The discrete excitations have perfectly and evenly distributed themselves across the entire topological geometry.

According to our **Law of Total Saturation**, because the volume of the vacuum is zero ($V(16) = 0$), the physical verdict is undeniable: **The number M_5 (31) is strictly PRIME.**

We did not divide 31 by 2, 3, or 5. We did not use multiplication. We simply let a discrete physical system evolve according to a deterministic rule of movement and collision, and nature revealed the answer through its own topological geometry.

4.4 Physical Detection of Composites: The M_{11} Anomaly ($p = 11$)

To rigorously demonstrate the discriminating power and absolute honesty of the Mersenne Chain Reactor (MCR), we examine the critical horizon for M_{11} ($p = 11$), where $T_c = 2^{11-1} = 1024$.

Unlike true prime dimensions ($p = 5, 7$) that inevitably achieve total spatial saturation, M_{11} ($2^{11} - 1 = 2047 = 23 \times 89$) is a well-known composite number. Therefore, if the foundational Information Physics laws of the MCR are universally accurate, the reactor must mathematically and physically *fail* to reach the unbroken $[1,1,1,1,1,1,1,1,1,1,1]$ topology. It must expose the "false prime".

Instead of navigating an exhaustive 1024-step trace, Table 1 captures the ultimate "Moment of Truth"the final dynamic cascade leading precisely to $T_c = 1024$.

As predicted by our deterministic framework, when the wave collapses at exactly $t = 1024$, the spatial topology does not synchronize into a Perfect Fit. Instead, the final physical superposition yields undeniable structural voids (zeros). This absolute spatial failure is the definitive physical

proof that the MCR operates as an impeccable sieve; it not only proves primality but flawlessly exposes composite numbers without requiring a single arithmetic division.

5 Hardware Implementation: The Mersenne Resonator

Bypassing the von Neumann bottleneck of conventional computational tests [2], the MCR's local ring dynamics naturally translate into a specialized hardware architecture: the **Mersenne Resonator** [4]. Conceptually sharing ground with quantum-inspired coherent Ising machines [5], it resolves primality not via ALU-driven arithmetic, but through localized physical state evolution and binary phase readout.

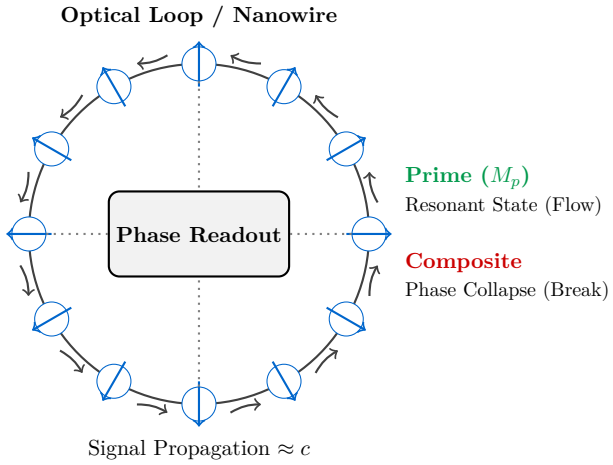


Figure 1: **Schematic of the Mersenne Resonator.** The device consists of p bistable nodes arranged in a cyclic lattice. The primality test is not an arithmetic calculation but a signal propagation event. If the signal sustains resonance after 2^{p-1} cycles, the number is Prime (Green). If the phase collapses due to avalanche interference, it is Composite (Red).

Operating on a continuous, cyclic topology of p bistable nodes (e.g., optical loops or superconducting nanowires), the resonator embeds the avalanche rules directly into its physical interconnections (*logic-in-memory*). Consequently, verification latency is completely decoupled from algorithmic complexity and strictly bounded by the signal's *time-of-flight* across the geometry. This physical propagation enables ultra-low-energy, sub-nanosecond prime generation for Post-Quantum Cryptography.

Ultimately, this theoretical continuous dynamics materializes into a direct, observable binary verdict, as conceptualized in the physical interface of the MCR-V1 (Figure 2).

Table 1: **The Climax of the M_{11} Trace.** Demonstrating the emergence of structural voids at exactly $T_c = 1024$, physically proving that the MCR accurately detects and falsifies composite numbers.

t	**Pump $t-1$**	**Physical Operations & Avalanche Result**
⋮	**(1016 steps of deterministic wave propagation omitted for brevity)**	⋮
1017	1016 (Hold)	$\hat{\sigma} \rightarrow$ [1,1,0,0,0,1,0,1,0,0,1] $+\Psi \rightarrow$ [1,1,0,1,0,0,1,1,1,1,0] Result $\rightarrow$ [**1**,**1**,**1**,**1**,**0**,**1**,**1**,**0**,**0**,**0**,**0**]
1018	1017 (Shift)	$\hat{\sigma} \rightarrow$ [0,1,1,1,1,0,1,1,0,0,0] $+\Psi \rightarrow$ [1,1,0,0,0,1,0,1,0,0,1] Result $\rightarrow$ [**1**,**0**,**0**,**0**,**0**,**0**,**0**,**1**,**1**,**0**,**1**]
1019	1018 (Hold)	$\hat{\sigma} \rightarrow$ [1,0,0,0,0,0,0,0,1,1,0,1] $+\Psi \rightarrow$ [1,1,1,1,0,1,1,0,0,0,0] Result $\rightarrow$ [**0**,**0**,**0**,**0**,**1**,**1**,**1**,**1**,**0**,**1**]
1020	1019 (Shift)	$\hat{\sigma} \rightarrow$ [1,0,0,0,0,1,1,1,1,1,0] $+\Psi \rightarrow$ [1,0,0,0,0,0,0,0,1,1,0,1] Result $\rightarrow$ [**1**,**1**,**0**,**0**,**0**,**1**,**1**,**0**,**1**,**0**,**0**]
1021	1020 (Hold)	$\hat{\sigma} \rightarrow$ [1,1,0,0,0,1,1,0,1,0,0] $+\Psi \rightarrow$ [0,0,0,0,1,1,1,1,1,0,1] Result $\rightarrow$ [**1**,**1**,**0**,**0**,**1**,**0**,**1**,**0**,**1**,**1**,**1**]
1022	1021 (Shift)	$\hat{\sigma} \rightarrow$ [1,1,1,0,0,1,0,1,0,1,1] $+\Psi \rightarrow$ [1,1,0,0,0,1,1,0,1,0,0] Result $\rightarrow$ [**1**,**1**,**0**,**1**,**0**,**0**,**0**,**0**,**0**,**0**,**0**]
1023	1022 (Hold)	$\hat{\sigma} \rightarrow$ [1,1,0,1,0,0,0,0,0,0,0] $+\Psi \rightarrow$ [1,1,0,0,1,0,1,0,1,1,1] Result $\rightarrow$ [**0**,**1**,**1**,**1**,**1**,**0**,**1**,**0**,**1**,**1**,**1**]
1024	1023 (Shift)	$\hat{\sigma} \rightarrow$ [1,0,1,1,1,1,0,1,0,1,1] $+\Psi \rightarrow$ [1,1,0,1,0,0,0,0,0,0,0] **VOIDS DETECTED (Composite!)** $\rightarrow$ [**0**,**0**,**0**,**1**,**0**,**0**,**1**,**1**,**0**,**1**,**1**]



Figure 2: **Conceptual Physical Embodiment of the MCR.** The device interface displays a Green Saturated Ring to signify global coherent resonance (verifying Primality, e.g., M_7), and a Red Fractured Ring indicating signal decoherence and void formation (verifying Compositeness, e.g., M_{11}). This provides a real-time, non-arithmetic verification output.

6 Discussion: The Physics of Prime Information

The Mersenne Chain Reactor (MCR) proposes a different view of primality testing. In the classical setting, the primality of a Mersenne number is established through arithmetic iteration. In the MCR, the same verdict is obtained through the evolution of a discrete physical state. The system does not rely on repeated modular updates as its central language. Instead, it evolves through signal propagation, superposition, and avalanche dynamics on a cyclic reactor.

This shift is conceptually important. In the usual computational framework, the outcome of a primality test is a symbolic or numerical output produced after many arithmetic steps. In the

MCR, the outcome is read from the final state of the reactor itself. More precisely, full saturation at the critical horizon corresponds to the prime case, whereas persistent structural voids correspond to the composite case. In this sense, the verdict is not merely computed; it is physically expressed by the state of the system.

This perspective places Mersenne primality into a state-based framework that is naturally aligned with ideas from natural computing and reaction-style dynamical systems. The reactor evolves in discrete time, its state changes locally, and the global decision emerges from the cumulative interaction of these local updates. The prime/composite distinction therefore appears as a difference in global phase behavior rather than only as an arithmetic yes/no output.

The contrast with classical large-scale searches is also instructive. Modern searches for large Mersenne primes, including the discovery of $M_{136279841}$, depend on extensive arithmetic processing at massive computational scale [10]. By comparison, the MCR suggests a different paradigm: the number is encoded into the topology of the reactor, and the verdict is extracted from state evolution rather than from long chains of explicit symbolic manipulation. This does not remove the need for rigor; rather, it changes the object of study from arithmetic workload to dynamical structure.

For this reason, the MCR may be viewed as an initial step toward a broader physics of prime information. The present work does not claim a universal physical law for all primes. However, it does show that, for the Mersenne family, primality can be reformulated in a precise dynamical language where prime means saturation and composite means unresolved void structure. That reformulation is the main conceptual contribution of this work.

Finally, this framework opens several directions for future study. These include sharper analytical descriptions of the reactor dynamics, comparisons with other discrete dynamical models, possible hardware realizations, and the use of early transient states as predictive signatures. Because the MCR produces structured temporal and spectral trajectories, it also provides a natural testbed for artificial intelligence and machine learning, especially for early prediction and data-driven classification of the final prime/composite outcome. In all cases, the central message remains the same: for Mersenne numbers, primality can be studied as a physical state transition.

7 Future Horizons: Toward a Universal Physics of Primes

The present work shows that a distinguished family of prime numbers, namely the Mersenne family, can be described through a precise physical law on a specific topology. This result gives a concrete example in which primality is not expressed only in arithmetic language, but also in the language of state evolution, propagation, and saturation. For this reason, it is scientifically reasonable to ask whether broader classes of primes may also admit related physical descriptions on more general topological structures.

From this viewpoint, the present study may be regarded as a first step toward a wider physics of primes. The claim here is not that such a general theory has already been established, but that the Mersenne case provides a rigorous model showing that this direction is mathematically meaningful and physically interpretable. In this sense, the work opens a new line of inquiry that

may be described as the information physics of primes.

This perspective may also have important consequences for post-quantum cryptography [11]. If very large prime structures can be verified through physical state evolution rather than only through long arithmetic procedures, then the cost model behind prime-based hardness assumptions may need to be revisited. In the same spirit, if factorization were ever shown to admit an analogous formulation through fast physical signal-processing mechanisms rather than traditional algebraic approaches [12], then some of the asymmetries underlying modern cryptographic security could require substantial re-evaluation.

The MCR also has a natural connection with artificial intelligence and machine learning. Its temporal and spectral outputs generate structured dynamical data that may support data-driven modelling of reactor evolution and early prediction of the eventual prime/composite outcome [13, 14]. In particular, learning systems trained on the early transient regime ($t \ll T_c$) may identify predictive signatures of the final saturation state well before the full cycle is completed. These methods would not replace the deterministic mathematical framework established in this work. Rather, they could provide complementary tools for early prediction, pattern extraction, and intelligent guidance within hybrid physical–computational architectures.

Finally, the spectral features observed in the reactor motivate broader mathematical comparison. We do not claim any direct equivalence between the MCR and the classical spectral theories associated with zeta statistics, random matrix theory, or quantum chaos. However, these theories provide an important comparative framework for future study [6–9]. The main point is more modest and more precise: the MCR introduces a new dynamical setting in which prime structure can be studied through physically interpretable state evolution.

Conclusion

This research establishes two fundamental results about prime numbers within the Mersenne family.

First, it proves that Mersenne primality is not merely an abstract arithmetic property, but a genuine physical state. Through the Mersenne Chain Reactor (MCR), a Mersenne prime is identified by total saturation of a discrete cyclic topology, whereas a composite Mersenne number is revealed by the persistence of structural voids. This is the central discovery of the present work: a concrete physical law for a distinguished family of prime numbers.

Second, this work introduces a new framework for primality verification. Instead of relying exclusively on prolonged arithmetic iteration, it reformulates the problem as a deterministic process of state evolution governed by explicit laws of motion on a discrete reactor. In this setting, the final verdict is produced by the physical configuration reached at the critical horizon. Verification is therefore determined by dynamical evolution and topological outcome, rather than by exhaustive symbolic manipulation alone.

Taken together, these results do more than provide a new method for studying large Mersenne primes. They open a new scientific direction in which primality can be investigated through information flow, state transitions, and interaction dynamics inside structured physical systems.

In this sense, the present work constitutes a first concrete step toward an information physics of prime numbers, and toward a broader study of the dynamical principles by which prime structure may emerge in nature.

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Competing Interests

The authors declare no competing interests, except that M. Ibrahim, B.M. Ibrahim, and R.M. Ibrahim are inventors on a patent application related to the Mersenne Chain Reactor (MCR).

Patents

The authors declare that aspects of the Mersenne Chain Reactor (MCR) are protected under U.S. Provisional Patent Application No. 63/981,494, filed on February 12, 2026, with the United States Patent and Trademark Office (USPTO). Title of Invention: *System and Method for Determining Primality via Physical Resonance Saturation in a Cyclic Lattice Architecture: The Mersenne Chain Reactor (MCR).*

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Supplementary Information

The Electronic Supplementary Material (ESM) accompanying this paper provides exhaustive deterministic traces, algorithmic implementations, and spectral analysis code to ensure full reproducibility. The ESM document is structured as follows:

- **Section S1: Algorithmic Implementation.** Provides the generalized Python kernel used to simulate the deterministic Information Physics of the MCR for any dimension p, bypassing arithmetic division entirely.
- **Section S2: Absolute Determinism ($p = 7$).** Contains the unabridged 64-step temporal trace, empirically demonstrating the perfect synchronization and total spatial saturation of M_7.
- **Section S3: Scaling Horizons ($p = 13$).** Presents the climax trace of M_{13} at the $T_c = 4096$ temporal horizon, physically confirming its primality without global collapse.

- **Section S4: The Ultimate Falsification ($p = 23$).** Details the climax trace of the composite anomaly M_{23} over 4 million discrete steps, demonstrating the persistent emergence of structural voids at $T_c = 4,194,304$.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- MersenneChainReactorScientificReportsSISUBMIT.pdf