

The Quantahedron: A Lattice-Based Framework for Unifying Quantum Mechanics and General Relativity through Angular Geometry

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Abstract

This paper introduces the Quantahedron—a 2D angular geometry whose symmetry and deviation encode mass, energy, and time. Within this framework, **mass, energy, and time emerge** from directional summation and angular deviation, and the speed of light squared (c^2) is a geometric invariant embedded in null-diagonal propagation.

The Quantahedron structure operates as a discrete lattice of vectorial propagation governed by amplitude normalization ($|V_x| + |V_y| = 1$). When $V_x = V_y$, mass vanishes, and propagation is light-like. Asymmetry from this null slope encodes mass via the relation $m = |\Delta\theta|$, while energy arises geometrically through $E = m \times c^2$.

By anchoring lattice units to known physical constants (e.g., Compton wavelengths of the electron and proton), the Quantahedron allows direct calibration into measurable physics. Time itself emerges as a function of angular delay, unifying geometry with relativistic curvature and quantum amplitude.

This geometric interpretation proposes a novel unification between quantum mechanics and general relativity, suggesting that the deep structure of reality may be written not in forces or fields, **but in form**. $E = mc^2$ becomes not an applied relation, but a geometric truth lived by the lattice.

1. Introduction: The Quantahedron and the Geometry of Mass-Energy-Time

Einstein's equation $E = mc^2$ revealed one of nature's most profound truths: that mass and energy are interchangeable (Einstein, 1905). Yet in most physical models, this identity is expressed algebraically, not geometrically. The equation is treated as a law to be applied, rather than a phenomenon to be emerged from structure.

This thesis introduces the **Quantahedron**: a discrete, **2D angular lattice** whose **symmetry and deviation** give rise to **mass, energy, and time** as **emergent geometric phenomena**. Unlike

conventional frameworks that depend on external constants, fields, or curvature metrics, the Quantahedron reveals these observables as **internal properties of form**, specifically, as a consequence of **vector summation and angular deviation** from **null symmetry**.

The choice of a two-dimensional lattice is intentional. A 2D structure enables **geometric clarity**, **minimal complexity**, and **direct visual representation** of vector dynamics. It serves as the **simplest dimensional substrate** where angular deviation, directional propagation, and temporal delay can be encoded without invoking higher-dimensional curvature or tensor calculus. **This dimensional economy isolates the fundamental relations of mass-energy-time in their purest geometric form.**

At its core, the **Quantahedron** is a **mirror-symmetric triangular lattice** constructed from **normalized vector pairs** (V_x, V_y) whose directional constraint satisfies $|V_x| + |V_y| = 1$. When vectors are perfectly balanced ($V_x = V_y = 0.5$), the trajectory forms a **45° diagonal**—a **null slope** representing **massless, light-like propagation**.

This null slope corresponds to a diagonal with angle $\pi/4$ radians, or 45° , in normalized space. It serves as the reference axis of perfect symmetry, where mass vanishes and propagation is light-like.

Deviations from this diagonal ($\Delta\theta \neq 0$) generate **mass**, defined geometrically as $m = |\Delta\theta|$. This **angular deviation** simultaneously induces **temporal delay** and alters **propagation geometry**, yielding energy via $E = m \times c^2$.

What emerges is a **purely geometric model** that encodes:

- **Energy** through **vectorial propagation**
- **Mass** through **angular deviation**
- **Time** through **propagation delay**
- c^2 as the **invariant symmetry** of **null-diagonal propagation**

By calibrating lattice units (ℓ_0, t_0) to known constants like the **Compton wavelengths** of the **electron**, **proton**, and **neutron**, the Quantahedron becomes **experimentally convertible** and **physically grounded**.

This model resonates with contemporary advances such as the **Amplituhedron** (Arkani-Hamed & Trnka, 2014), which seeks to reframe particle interactions using **geometric amplitudes** rather than Feynman diagrams. Like the Amplituhedron, the Quantahedron proposes that the **laws of physics** may not arise from **force or field**, but from **symmetry, constraint, and form**.

This thesis presents the **Quantahedron** as a **unifying geometric framework** that bridges the gap between **quantum mechanics** and **general relativity**, offering a **visual and mathematical structure** in which **mass-energy-time relationships** are not imposed, but **inevitably emerged from geometry itself**.

2. The Lattice Structure of the Quantahedron

The **Quantahedron** is a discrete, two-dimensional angular lattice composed of normalized vector pairs (V_x, V_y) , arranged into a triangular field. Each node in this field serves as a point of directional propagation governed by local symmetry, constraint, and angular geometry.

The Quantahedron does not describe space as a continuum, it discretizes motion into angular memory units. Each directional pair satisfies a foundational rule of conservation:

$$|V_x| + |V_y| = 1$$

This condition ensures that all vectorial propagation is **bounded and normalized**, mirroring the **unitarity principle** in quantum mechanics. The sum of directional components at each node defines the lattice's amplitude constraint and underpins its physical behavior.

2.1 Directional Components and Triangle Units

At every node, two orthogonal directional vectors are defined:

- V_x – horizontal component of propagation
- V_y – vertical component of propagation

Together, they form the legs of a **right triangle**. The diagonal or hypotenuse is denoted:

$$C_{xy} = \sqrt{(V_x^2 + V_y^2)}$$

This triangle is the **elementary geometric unit of the Quantahedron**, encoding direction, deviation, and energy simultaneously. The vector triangle does not merely describe motion, it records the **structural tension** between balance and imbalance.

Figure 1 consolidates the amplitude constraint, vectorial composition of C_{xy} , and the null slope geometry at the heart of the Quantahedron lattice.

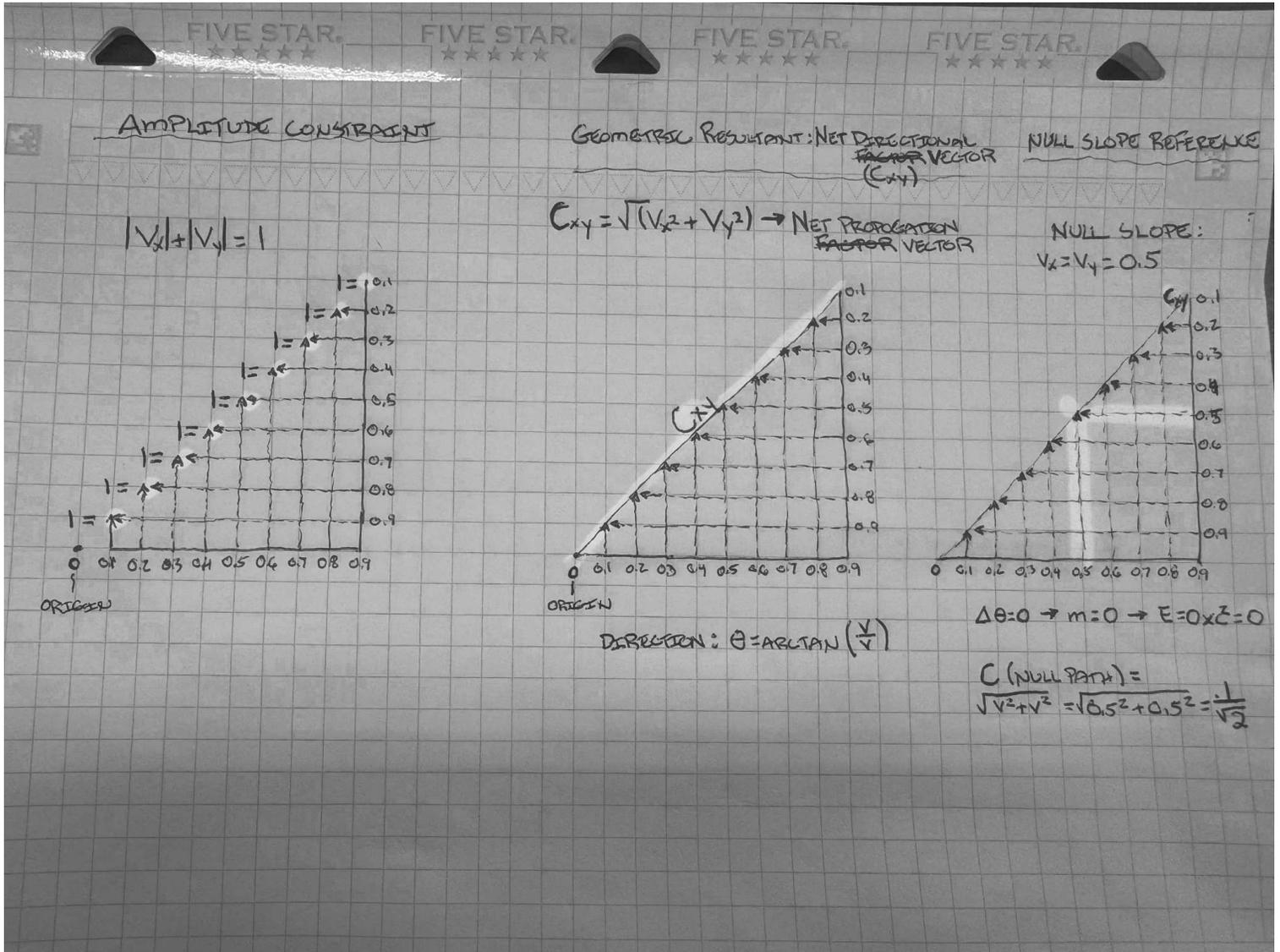


Figure 1. Foundational triangle definitions: (Left) Amplitude constraint ($|V_x| + |V_y| = 1$), (Center) net propagation vector C_{xy} , (Right) null slope geometry ($V_x = V_y = 0.5$).

2.2 Null Symmetry and the Invariant Diagonal

When $V_x = V_y = 0.5$, the trajectory follows a **45° diagonal path** known as the **null slope**. This configuration is maximally symmetric and corresponds to **light-like propagation**, in which:

- **Angular deviation ($\Delta\theta$) = 0**
- **Mass (m) = 0**
- **Propagation speed is maximal ($c^2 = 1$, a normalized unit)**
- **No internal delay is induced**

This null slope defines the **invariant symmetry** of the lattice. It acts as the internal reference axis of the Quantahedron, just as the speed of light acts as the invariant in spacetime (*Einstein, 1916; Misner, Thorne, & Wheeler, 1973*). Geometrically, this diagonal embodies the lattice's internal definition of c^2 : a propagation speed encoded not as velocity, but as the symmetry slope of perfect balance. All physical quantities—mass, energy, and time, arise from deviation away from this central path.

2.3 Angular Deviation and Emergent Mass

When the vector pair becomes unbalanced, i.e., $|V_x| \neq |V_y|$ —the resulting trajectory tilts away from the null slope. This **angular asymmetry** is measured as:

$$\Delta\theta = \arctan(V_y / V_x) - \pi/4$$

Figure 2 shows that mass is symmetric around the null slope, with equal $|\Delta\theta|$ producing identical energy regardless of the propagation side.

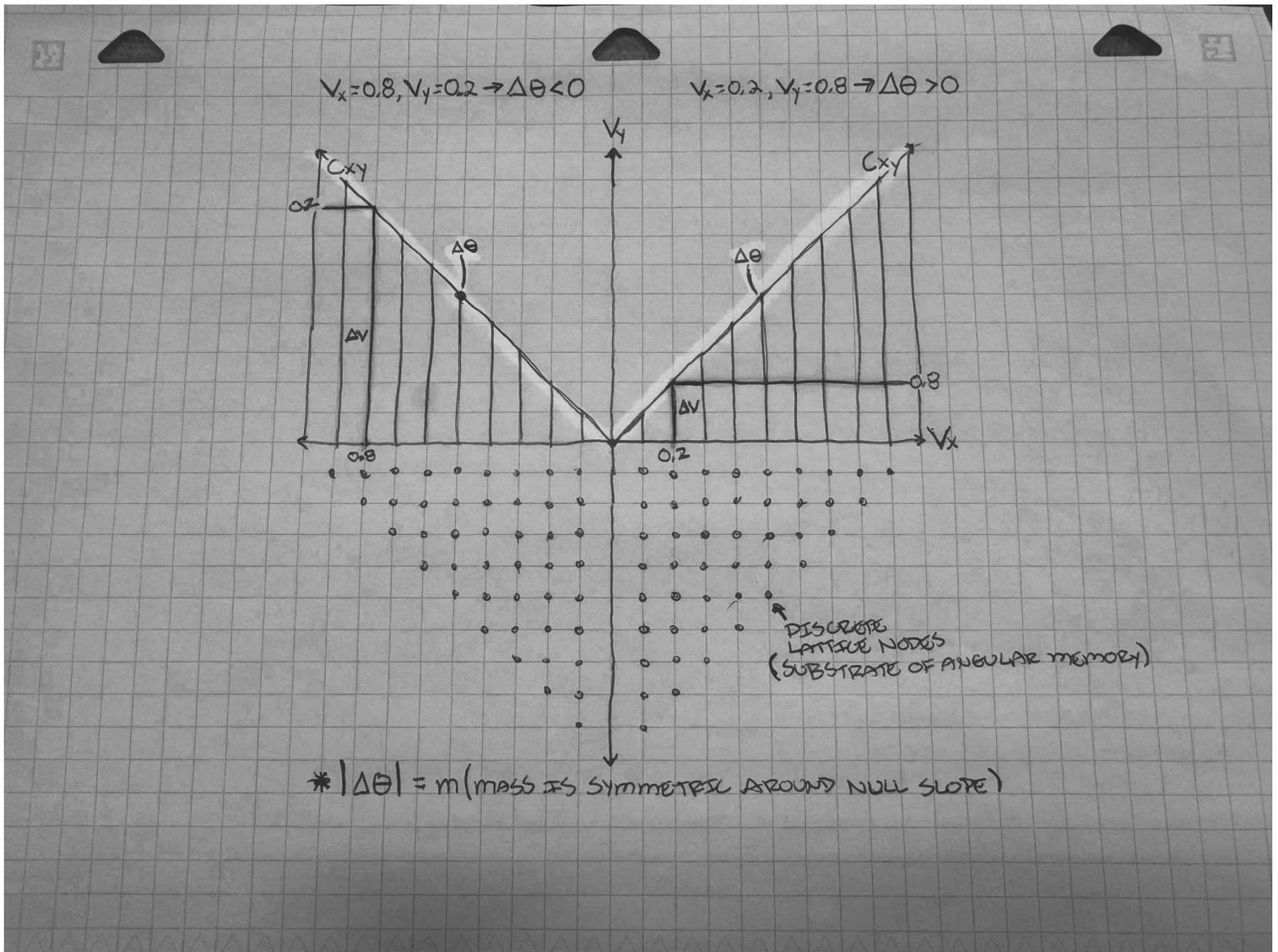


Figure 2. Mirror symmetry of angular deviation. Both leftward and rightward deviations from the null slope yield equal $|\Delta\theta| = m$. This symmetry supports bidirectional encoding of mass and energy.

The magnitude of this deviation defines the mass:

$$m = |\Delta\theta|$$

In this view, mass is not a fundamental substance, but a memory of imbalance, a geometric tension encoded in directional asymmetry. The more a trajectory deviates from null symmetry, the more energy is required to maintain it. Thus, mass arises as stored directional resistance to perfect balance.

This framework geometrically enacts the mass-energy relationship:

$$E = m \times c^2$$

= $|\Delta\theta| \times$ (diagonal symmetry)

Mass is not imposed, it is born from the structure's own angular displacement.

2.4 Time as Angular Delay

In conventional models, time is treated as a fundamental axis, uniform and external to the structure of space. In the **Quantahedron**, time is not an independent dimension. It is a consequence of **angular geometry**.

When directional vectors are imbalanced, the trajectory tilts away from the null slope. As this angular deviation increases, the vertical component (V_y) grows disproportionately larger than the horizontal component (V_x). The result is a **steepened path** that covers less horizontal ground per unit of vertical change, inducing what can be described as a **directional delay**.

This delay is **geometrically induced**, not externally imposed. In lattice terms:

- **Greater $\Delta\theta$** → slower directional progression → **time dilation**
- **Smaller $\Delta\theta$** → faster directional progression → **temporal contraction**

Thus, time is **emergent**, encoded in the lattice as a **function of imbalance**. It is not separate from space, but arises from the **shape** of motion.

In this framework, **time and mass** become **entangled expressions of angular asymmetry**. When $\Delta\theta = 0$, no internal delay occurs, motion is timeless. As angular confinement increases, progression across the lattice slows, and **duration emerges from geometry**.

Angular propagation is mirrored across the lattice center, with reversed paths encoding equal energy under opposite directional tilt (**see Fig. 3**)

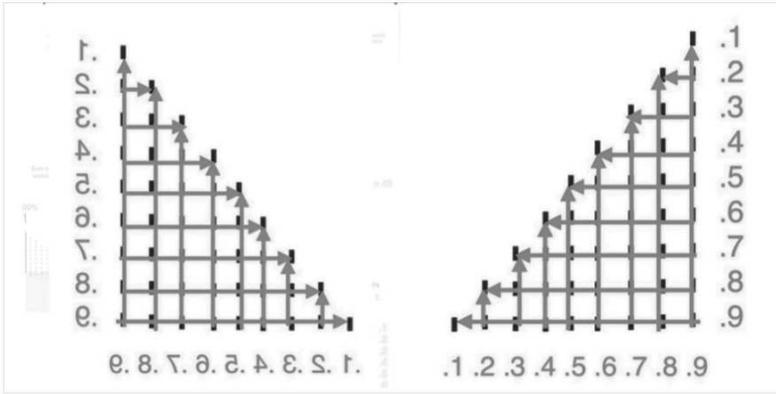


Figure 3. Bidirectional lattice propagation, encoding time dilation and contraction symmetrically. Angular memory is conserved across mirror domains.

3. The Geometric Manifestation of $E = mc^2$

The Quantahedron provides a direct, visual enactment of the mass-energy equivalence. In this framework, $E = mc^2$ is not symbolic, it is **structurally realized** within each triangle of the lattice.

Each of the equation's components emerges from geometry:

- **E**: Total directional propagation across the lattice
- **m**: Angular deviation ($\Delta\theta$) from null symmetry
- **c^2** : The invariant geometric identity of the 45° diagonal (null slope)

3.1 Light-Like Propagation ($\Delta\theta = 0$)

When vectors are balanced ($V_x = V_y = 0.5$), the resulting trajectory lies along the null slope. In this condition:

- $\Delta\theta = 0$
- $m = 0$

- $E = 0 \times c^2 = 0$

This corresponds to **massless, light-speed propagation**, a state of perfect symmetry and unimpeded motion. No energy is stored because there is no deviation.

Figure 4 confirms that when $V_x = V_y = 0.5$, propagation follows the null diagonal ($\Delta\theta = 0$), indicating a massless, light-like state.

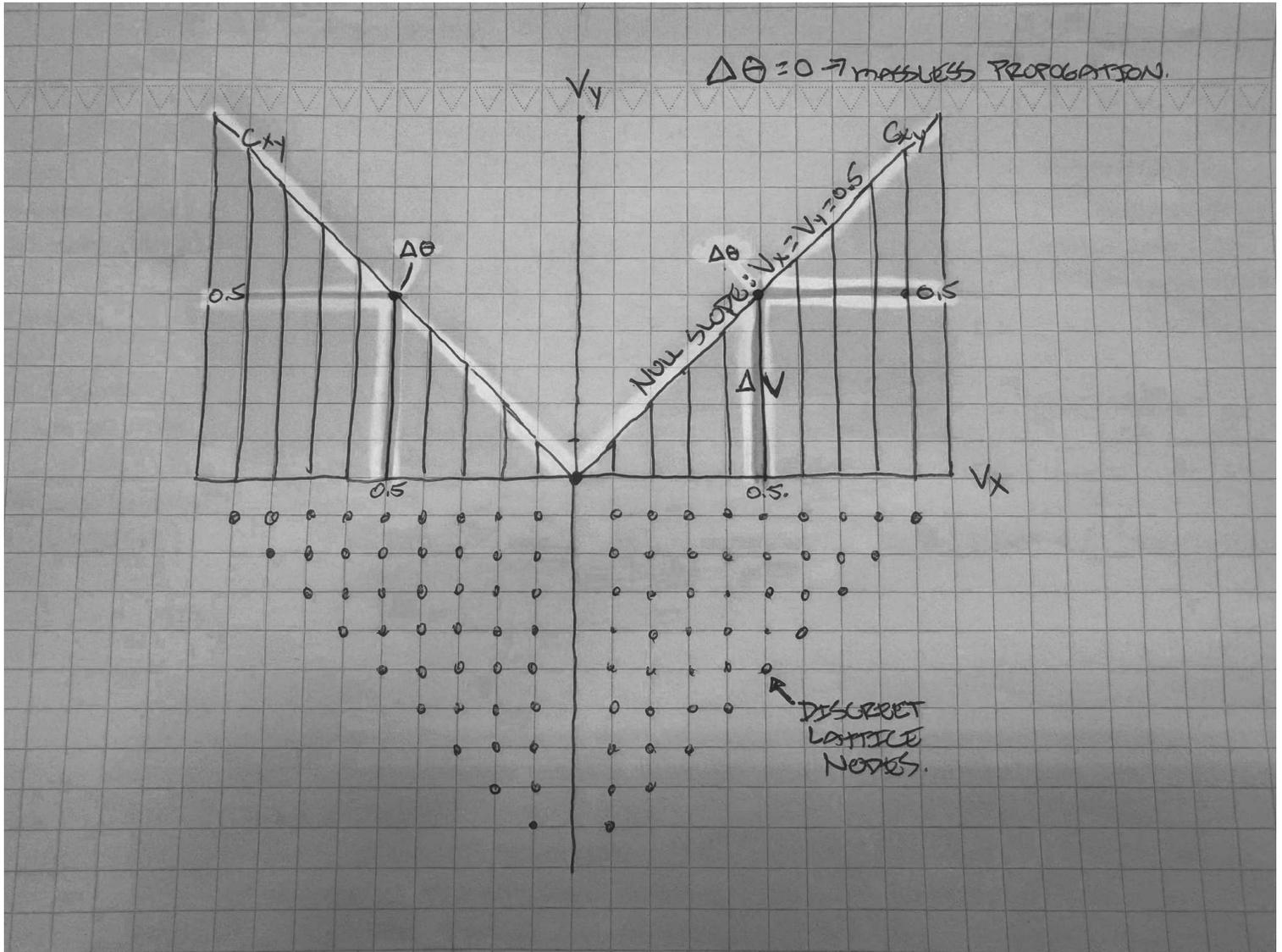


Figure 4. Balanced vector components ($V_x = V_y = 0.5$) define the null slope with $\Delta\theta = 0$. This results in massless propagation without energy storage.

3.2 Massive Trajectories ($\Delta\theta \neq 0$)

As directional balance is lost, angular deviation increases. For example:

- $V_x = 0.3, V_y = 0.7$
- $\Delta\theta = \arctan(0.7 / 0.3) - \pi/4 \approx +0.38 \text{ rad}$

This deviation yields a nonzero mass:

$$m = |\Delta\theta| \approx 0.38 \text{ (unscaled)}$$

And thus a nonzero energy:

$$E = m \times c^2$$

The **larger** the deviation from the null slope, the **greater** the confinement of energy. Mass becomes a **geometric consequence**, and energy a **result of structure under constraint**.

While $c^2 = 1$ is used for geometric normalization within the lattice, physical conversion reintroduces dimensional units for testability (Einstein, 1905; Misner, Thorne, & Wheeler, 1973). This allows the model to bridge abstract symmetry with real-world physics by restoring the full dimensional identity of $c^2 = (3.00 \times 10^8 \text{ m/s})^2$ in experimental contexts.

As shown in Fig. 5, the geometric triangle formed by the null slope (base), angular deviation (height), and energy (area) directly enacts the $E = mc^2$ relation as a spatial memory triangle.

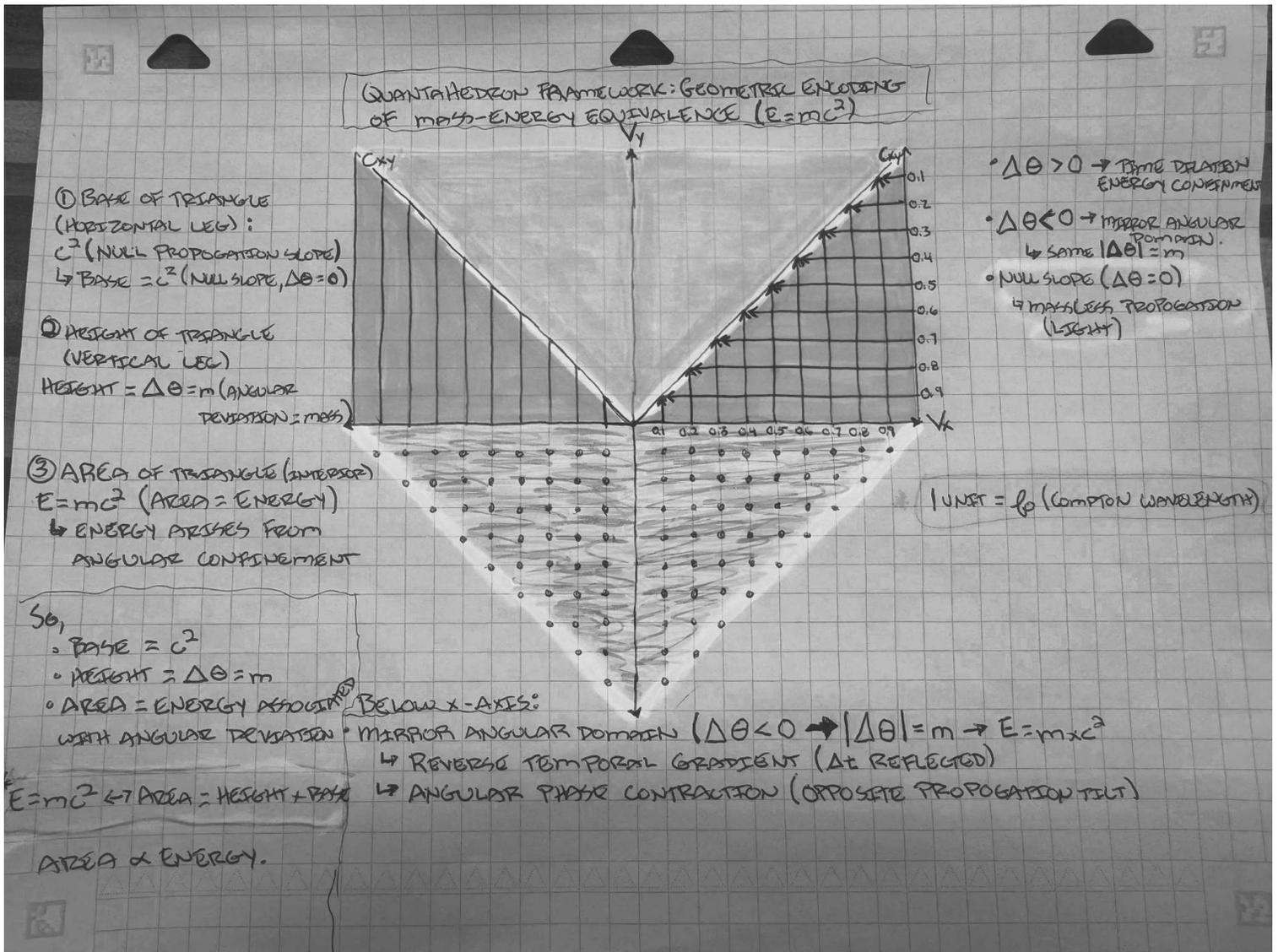


Figure 5. The Quantahedron triangle enacts $E = mc^2$ geometrically. Base = c^2 (null propagation slope), height = $\Delta\theta = m$ (angular deviation), and area = energy stored. Mirror domains below the x-axis encode angular reversal but preserve $|\Delta\theta| = m$.

As shown in **Figure 6**, both positive and negative angular deviations from the null slope encode symmetric mass and energy. The Quantahedron preserves this mirror logic across its full structure.

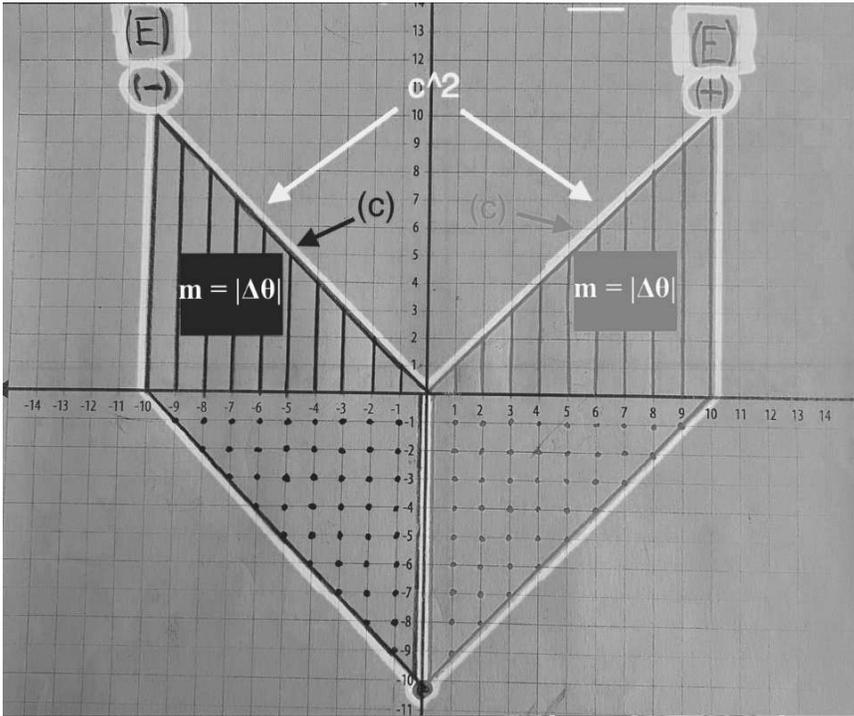


Figure 6. Symmetric Angular Deviation and Energy Confinement Across the Null Slope.

This diagram illustrates mirror-symmetric domains of angular deviation ($\Delta\theta$) on either side of the null slope (c^2), where each triangular region encodes mass as geometric deviation: $m = |\Delta\theta|$. The left region (negative $\Delta\theta$) and the right region (positive $\Delta\theta$) produce equivalent energy (E) through symmetric confinement above the null diagonal. The vertical axis represents the invariant propagation slope c^2 , while each triangle's area reflects directional resistance. The bottom half encodes memory symmetry and amplitude conservation through discrete lattice dots, suggesting conserved propagation across mirrored domains. Together, these mirrored structures express $E = m \times c^2$ as a geometric memory of angular deviation and its bidirectional tension from balance.

1. Visual Summary Table:

| Concept | Formula | Geometric Meaning |
|------------|-----------------------------------|-------------------|
| Mass | $m =$ | $\Delta\theta$ |
| Energy | $E = m \times c^2$ | Area of triangle |
| Time | $\Delta t = t_0 \times (V_y/V_x)$ | Angular delay |
| Null Slope | $V_x = V_y$ | Perfect symmetry |

3.3 Energy as Spatial Memory

In the Quantahedron, energy is not a value applied to the system. Rather, it's framework views each triangle as a *quantal cell*, a discrete unit of directional resistance, storing energy as angular displacement from symmetry, and serving as a *Memory Triangle*, embodying $\Delta\theta$, C_{xy} , and directional constraint.

It is a **spatial encoding of tension**, a product of deviation from balance:

- A balanced vector transmits energy **freely**
- An imbalanced vector stores energy through **angular resistance**

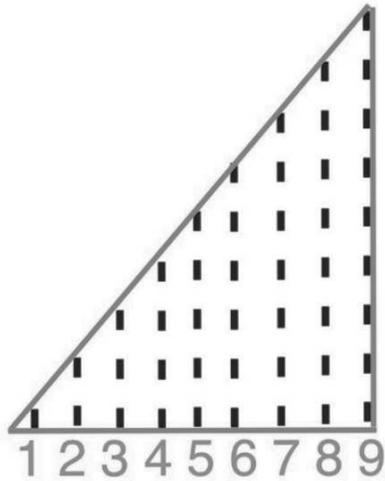
The **right triangle formed at each node** becomes the **cell of energetic storage**, with:

- Hypotenuse = net direction (C_{xy})
- Area = energy density
- Angle = memory of deviation

Each triangle is a **quantum of emergence** (*Wheeler, 1982*), encoding motion, tension, and time

simultaneously. When seen across the lattice, $E = mc^2$ is not just true, it is **enacted by the field itself**. Each triangle not only encodes energy, but also preserves directional asymmetry, suggesting a connection between energy confinement and informational entropy.

Figure 7 metaphorically represents how angular confinement accumulates energy within discrete triangle units.



$$1+2+3+4+5+6+7+8+9 = 45$$

Figure 7. Discrete triangle summation visualizing the accumulation of directional energy across lattice cells. Each row of the triangle corresponds to incremental angular deviation.

4. Temporal Emergence from Angular Deviation

In classical physics, time is treated as a continuous parameter, absolute in Newtonian systems or relative in Einsteinian spacetime. Yet in the **Quantahedron**, time is neither a pre-existing background nor an independent axis. Instead, time emerges from **geometric configuration**. It is a **memory of angular deviation**—a delay created by the shape of motion.

Each propagation step within the lattice occurs along a direction defined by (V_x, V_y) . When this direction deviates from perfect diagonal symmetry ($V_x = V_y$), the **horizontal velocity component shrinks**, and the path steepens. The steeper the path (higher V_y / lower V_x), the more time is experienced per lattice step. This encodes a geometric dilation analogous to proper time in general

relativity and induces an **internal delay** that functions as **proper time**.

Mathematically:

$$\Delta t \approx t_0 \times (V_y / V_x)$$

Here, t_0 is the base time unit defined by the lattice (ℓ_0 / c), and the ratio V_y / V_x scales the temporal delay. As V_x **decreases**, the **delay increases**, directly encoding **time dilation** as a **function of angular geometry**. As the vertical component increases relative to the horizontal, the lattice step becomes 'steeper,' reducing net progress per unit time, mirroring relativistic time dilation in curved spacetime.

This mechanism parallels the curvature-induced time dilation in general relativity (*Einstein, 1916; Misner, Thorne, & Wheeler, 1973*), where gravitational mass warps spacetime and slows time. But in the Quantahedron, this delay arises **not from external curvature**, but from **internal angular confinement**. The result is equivalent: **the greater the deviation from the light-like path, the slower the progression of time**.

Time, then, is not linear, it is **vectorial**. It does not flow independently, it is **drawn from deviation**. In this model, **mass and time are twin expressions** of the same geometric memory: one encoded as spatial curvature, the other as directional delay.

Figure 8 illustrates how angular steepening increases V_y/V_x , leading to time dilation, while contraction occurs for $\Delta\theta < 0$.

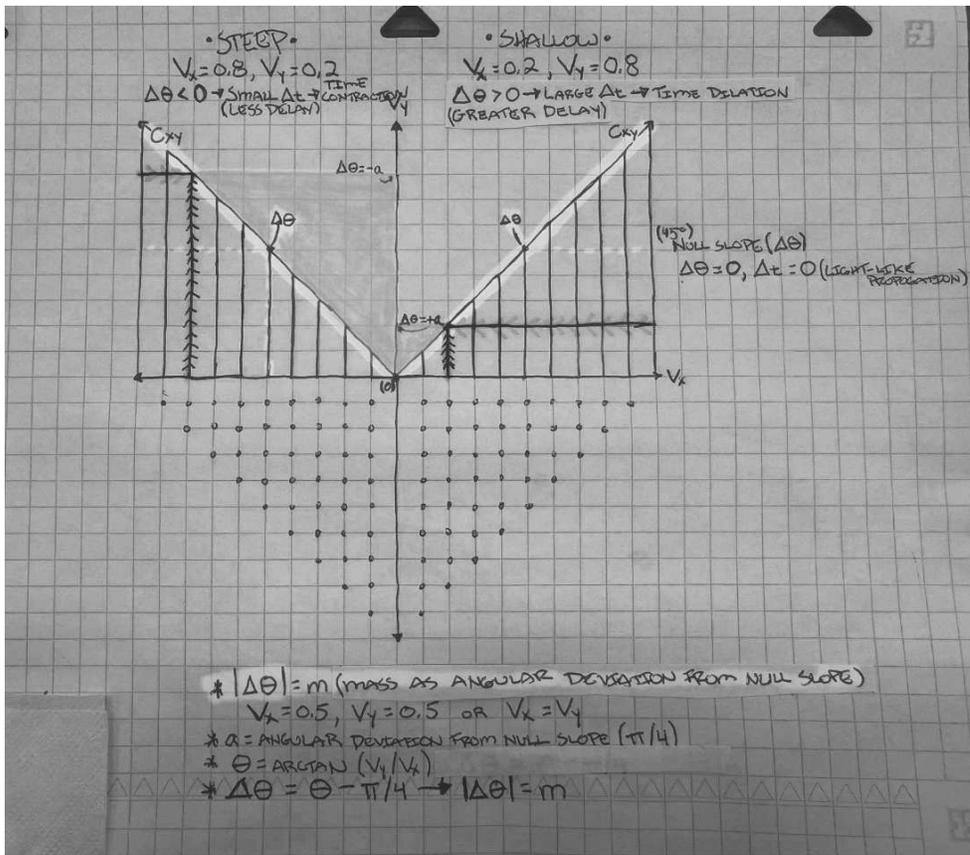


Figure 8. Lattice geometry showing angular deviation ($\Delta\theta$) and its impact on temporal progression. Steep paths ($V_x = 0.2, V_y = 0.8$) result in $\Delta\theta > 0$ and greater Δt (time dilation). Shallow paths ($V_x = 0.8, V_y = 0.2$) yield $\Delta\theta < 0$ and temporal contraction.

- $\Delta\theta > 0$ (steepening \rightarrow time dilation)
- $\Delta\theta < 0$ (shallow \rightarrow time contraction)
- Symmetric $|\Delta\theta|$, same mass.

Philosophically, this suggests time is not an external clock but an internal echo of imbalance. In the absence of deviation, no temporal progression occurs. Thus, time itself is born from asymmetry, a delay braided into geometry.

5. Conclusion: Geometry as Origin

This thesis has presented the **Quantahedron** as a geometric framework in which mass, energy, and time emerge not as imposed variables, but as **consequences of angular structure**. Ultimately,

mass, energy, and time may not be primary quantities, but geometric memories, preserved through angular deviation within a field of symmetry. Within this lattice:

- **Energy (E)** arises from **vectorial propagation**
- **Mass (m)** is encoded as **angular deviation ($\Delta\theta$)**
- c^2 represents the **diagonal symmetry** of null-slope motion
- **Time (t)** emerges from **internal delay due to directional steepening**

Together, these form the lattice's **energetic grammar**, a geometric enactment of $E = mc^2$, where the equation is not applied but **lived** by the structure.

The Quantahedron suggests that **space, time, and matter** may all be **epiphenomena** of a deeper, combinatorial geometry, one that does not rely on fields, forces, or curvature tensors, but on **angle, balance, and propagation**.

This proposal aligns with modern efforts to **geometrize physics** at its foundations, including the **Amplituhedron, loop quantum gravity, and twistor theory** (*Arkani-Hamed & Trnka, 2014; Rovelli, 1998; Penrose, 1967*). Like these models, the Quantahedron replaces traditional mechanisms with structure, suggesting that **reality itself may be a lattice of constraint, symmetry, and memory**.

The Quantahedron grid (**Fig. 9**) reinforces the conservation of amplitude and energy flow within the lattice topology.

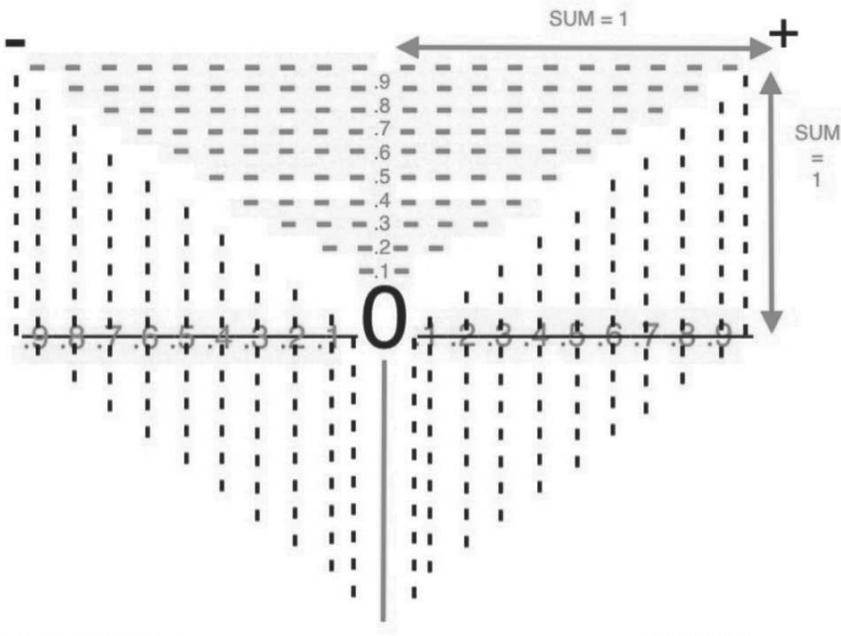


Figure 9. Full angular memory lattice. Vertical and horizontal sums encode propagation symmetry and quantized conservation, with central zero-point origin.

By anchoring this framework to known physical constants, such as the Compton wavelengths of the electron, proton, and neutron, the model becomes **quantitatively testable**. The emergence of mass, energy, and time is no longer mysterious, it is **measurable**, and grounded in form.

Toward Unification

Modern physics has long been divided by a paradox: **quantum mechanics** governs the subatomic with probabilistic amplitudes and uncertainty, while **general relativity** describes the macroscopic universe as smooth curvature and determinism. Efforts to reconcile these frameworks have produced strings, loops, amplitudes, and networks, but a true unifying language has remained elusive.

The **Quantahedron** offers a new geometric language, **not by adding more complexity, but by returning to the foundational essence of structure: angle, balance, and form**. It does not presume a continuum of spacetime, nor does it rely on force-carriers or virtual particles. Instead, it encodes physical phenomena as **emergent expressions of symmetry and deviation** within a discrete vector lattice.

In this view:

- **Quantum behavior** arises from **amplitude constraints** within vector summation
- **Relativistic effects** emerge as **directional confinement and angular delay**
- The **speed of light (c)** is not imposed—it is the **natural slope of perfect symmetry**
- **Mass and time** are not fundamental—they are **geometric memories of deviation**

Thus, the Quantahedron does not unify quantum mechanics and general relativity by overlaying their mechanics, but by **revealing them as emergent shadows of the same underlying geometry.**

Where the **Amplituhedron** geometrizes scattering amplitudes in higher dimensions, the **Quantahedron** geometrizes the **mass-energy-time continuum** in two. One encodes interaction, the other encodes being. Together, they suggest a broader shift in the physics paradigm: **from force to form, from fields to angles, from algebra to symmetry.**

The equation $E = mc^2$ is not symbolic — it is the memory signature of deviation. This unification is not a merger of two incompatible systems, it is the recognition that they were **never truly separate.** Both arise from structure. At the heart of structure lies a triangle.

A vector.

A deviation.

The Quantahedron.

As shown in **Fig. 10**, the angular encoding of the Quantahedron resembles the shape structure of the Amplituhedron, suggesting a geometric kinship.

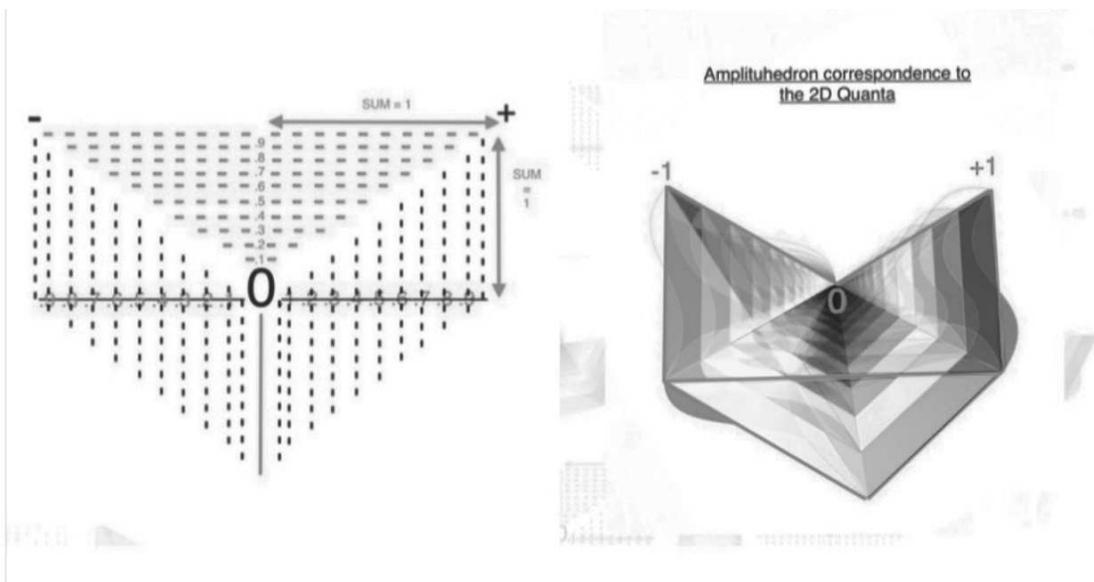


Figure 10. Left: 2D Quanta lattice with balance across zero-point symmetry. Right: Amplituhedron correspondence, suggesting a mirrored geometric logic.

This correspondence hints at a unifying geometric language—where one lattice encodes event (amplitude), and the other, existence (energy-memory). Where the Amplituhedron encodes scattering interactions through geometric amplitudes, the Quantahedron encodes the existential conditions of mass and time—one is the geometry of event, the other, of being.

Future Directions

As computational modeling matures, the Quantahedron could inform:

- New visual approaches to **quantum field simulations**
- Angular lattice models for **quantum computing architectures**
- A framework to unify **entanglement, curvature, and propagation delay**
- GPU visualization of **entropic dispersion**—mapping how asymmetry spreads across the lattice—may inform thermodynamic reinterpretations.
- *Future work may explore GPU-accelerated simulations of the Quantahedron lattice, enabling real-time visualization of energy confinement, angular deviation, and emergent time delay. These dynamic animations could offer both intuitive insight and experimental modeling of mass-energy-time behavior within the lattice framework.*

It may even point toward a deeper principle: that **form precedes function**, and that the universe is not merely described by geometry, but **generated by it**.

Appendix: Calibration and Physical Scaling of the Quantahedron Lattice

This appendix outlines how the Quantahedron lattice is anchored to known physical constants. By calibrating the lattice using the electron's Compton wavelength and angular deviation, we translate geometric abstractions into testable physical units of length, time, mass, energy, and frequency. The model's core claim—that mass, energy, and time emerge from vectorial geometry—becomes physically grounded and experimentally accessible.

1. Defining Physical Units for the Lattice

Length Unit (ℓ_0):

We anchor the lattice length to the **Compton wavelength of the electron**, a fundamental quantum constant:

$$\ell_0 = \lambda_e = h / (m_e \times c) \approx 2.426 \times 10^{-12} \text{ meters}$$

(Einstein, 1905; Misner, Thorne, & Wheeler, 1973)

This defines one lattice step as ~ 2.426 picometers, forming the base spatial resolution of the Quantahedron field.

Time Unit (t_0):

Assuming that diagonal propagation follows light-speed:

$$t_0 = \ell_0 / c = (2.426 \times 10^{-12}) / (3.00 \times 10^8) \approx 8.09 \times 10^{-21} \text{ seconds}$$

Each lattice step takes approximately 8 attoseconds to propagate along the null slope.
(Einstein, 1916; Misner et al., 1973)

Angular Deviation Unit (θ_0):

We define mass as arising from deviation from perfect diagonal symmetry ($\pi/4$ radians):

$$m = |\Delta\theta - \pi/4| \times k_m$$

(Wheeler, 1982; Rovelli, 1998)

This relation translates geometric asymmetry directly into physical mass via a scaling constant k_m .

2. Geometric Definitions Within the Lattice

Null Slope (c):

When $|V_x| = |V_y| = 0.5$, propagation follows a 45° diagonal with maximum symmetry:

- $c^2 = 1$ (normalized)
- $\Delta\theta = 0 \rightarrow$ massless state
- Hypotenuse: $|C_{xy}| = \sqrt{0.5}$

This symmetry mirrors light-like propagation and defines the invariant limit of the lattice, analogous to the role of light-speed in relativity.

(Einstein, 1916; Misner et al., 1973)

Angular Deviation ($\Delta\theta$):

Deviation from null slope is defined by:

$$\Delta\theta = \arctan(V_y / V_x)$$

Mass arises from the magnitude of this deviation:

$$m = |\Delta\theta| = |\arctan(V_y / V_x) - \pi/4|$$

(Wheeler, 1982; Rovelli, 1998)

Directional Constraint Rule:

All lattice nodes obey:

$$|V_x| + |V_y| = 1$$

This ensures normalized, bounded propagation, analogous to the unitarity constraint in quantum mechanics.

(Peskin & Schroeder, 1995; Arkani-Hamed & Trnka, 2014)

Triangle Representation:

Each pair of directional components (V_x, V_y) forms a right triangle with:

- Legs: V_x, V_y

- Hypotenuse: C_{x_Y}
 - Area: Energy potential
 - Symmetry = massless
 - Skew = confinement
- (Wheeler, 1982)

Time as Angular Delay:

Time is not a separate axis but emerges from angular steepening:

$$\Delta t \approx t_0 \times (V_Y / V_x)$$

This geometrically induced delay reflects relativistic time dilation without invoking external curvature.

(Einstein, 1916; Misner et al., 1973)

3. Calibrating to the Electron: Worked Example

We now demonstrate full physical calibration using the electron.

Step 1: Lattice Length

$$\ell_0 = \lambda_e \approx 2.426310 \times 10^{-12} \text{ m}$$

(CODATA, 2022)

Step 2: Time Step

$$t_0 = \ell_0 / c = 2.426310 \times 10^{-12} / 299,792,458 \approx 8.0933 \times 10^{-21} \text{ s}$$

Step 3: Assign Electron Mass via Angular Deviation

Choose a small deviation:

$$\Delta\theta = \pi/4 + 0.01 \text{ rad}$$

$$|\Delta\theta - \pi/4| = 0.01 \text{ rad}$$

Using:

$$m = |\Delta\theta - \pi/4| \times k_m$$

Let $m = m_e = 9.109 \times 10^{-31}$ kg

Solve:

$$k_m = m_e / 0.01 = 9.109 \times 10^{-29} \text{ kg/rad}$$

(CODATA, 2022)

Step 4: Electron Energy

$$E = m \times c^2$$
$$= (9.109 \times 10^{-31}) \times (3.00 \times 10^8)^2$$
$$\approx 8.187 \times 10^{-14} \text{ joules}$$

(Einstein, 1905; CODATA, 2022)

Step 5: Time Dilation from Asymmetry

Given $V_x = 0.3$, $V_y = 0.7$:

$$\Delta t = t_0 \times (V_y / V_x)$$
$$\Delta t = (8.0933 \times 10^{-21}) \times (0.7 / 0.3) \approx 1.8885 \times 10^{-20} \text{ s}$$

This demonstrates geometric encoding of temporal delay.
(Einstein, 1916)

4. Lattice Density and Frequency

Spatial Density (ρ_x):

$$\rho_x = 1 / \ell_0 = 1 / (2.4263 \times 10^{-12}) \approx 4.122 \times 10^{11} \text{ steps/meter}$$

Temporal Frequency (f_t):

$$f_t = 1 / t_0 = 1 / (8.0933 \times 10^{-21}) \approx 1.236 \times 10^{20} \text{ steps/second}$$

Diagonal Density (ρ_e):

$$\ell_{\text{diag}} = \sqrt{2} \times \ell_0 \approx 3.429 \times 10^{-12} \text{ m}$$

$$\rho_e = 1 / \ell_{\text{diag}} \approx 2.917 \times 10^{11} \text{ diagonal steps/meter}$$

Table A1: Quantahedron Physical Conversion Summary

| Quantity | Symbol | Value/Formula | Units |
|-----------------------|----------------------|--|---------------|
| Lattice unit length | ℓ_0 | 2.426×10^{-12} | meters |
| Lattice time step | t_0 | $\ell_0 / c \approx 8.09 \times 10^{-21}$ | seconds |
| Spatial density | ρ_x | $1 / \ell_0 \approx 4.12 \times 10^{11}$ | steps/meter |
| Temporal frequency | f_t | $1 / t_0 \approx 1.236 \times 10^{20}$ | steps/second |
| Diagonal step length | ℓ_{diag} | $\sqrt{2} \times \ell_0 \approx 3.429 \times 10^{-12}$ | meters |
| Diagonal step density | ρ_e | $1 / \ell_{\text{diag}} \approx 2.917 \times 10^{11}$ | steps/meter |
| Mass scaling constant | k_m | $m_e / 0.01 \approx 9.109 \times 10^{-29}$ | kg per radian |
| Electron rest energy | E_e | 8.187×10^{-14} | joules |
| Time dilation formula | Δt | $t_0 \times (V_y / V_x)$ | seconds |

Table A2: Quantahedron Lattice SI Conversion Chart with Electron

Quantahedron Lattice SI Conversion Chart

| # | Lattice Quantity | Symbol | Definition | SI Unit | Approximate Value (Electron) |
|---|------------------------------------|----------------|---------------------------------|----------------|------------------------------|
| 1 | ℓ_0 (unit length) | ℓ_0 | $\lambda_e = h / (m_e \cdot c)$ | meters (m) | 2.426×10^{-12} m |
| 2 | t_0 (unit time) | t_0 | ℓ_0 / c | seconds (s) | 8.093×10^{-21} s |
| 3 | $\Delta\theta$ (angular deviation) | $\Delta\theta$ | $\arctan(V_y / V_x) - \pi/4$ | radians (rad) | ≈ 0.01 rad (example) |
| 4 | m (mass) | m | $ \Delta\theta $ | kilograms (kg) | 9.109×10^{-31} kg |
| 5 | E (energy) | E | $m \cdot c^2$ | joules (J) | 8.187×10^{-14} J |

Table A3: Units

| Quantity | Formula | Units |
|----------------|------------------------------|----------------|
| $\Delta\theta$ | $\arctan(V_y / V_x) - \pi/4$ | radians |
| m | | $\Delta\theta$ |
| E | $m \times c^2$ | J |
| Δt | $t_0 \times (V_y / V_x)$ | s |

Section 4.1: Lattice-to-SI Conversion Chart

$\Delta\theta$ (angular deviation)

Formula:

$$\Delta\theta = \arctan(V_y / V_x) - \pi/4$$

Units:

$$\Delta\theta = \text{radians (rad)}$$

$$V_y / V_x = \text{dimensionless}$$

m (mass from deviation)

Formula:

$$m = |\Delta\theta| \times k_m$$

Units:

$$m = \text{kilograms (kg)}$$

$$\Delta\theta = \text{radians (rad)}$$

$$k_m = \text{kg/rad}$$

E (energy from mass)

Formula:

$$E = m \times c^2$$

Units:

$$E = \text{joules (J)}$$

$$m = \text{kg}$$

$$c^2 = \text{m}^2/\text{s}^2$$

Δt (time dilation)

Formula:

$$\Delta t = t_0 \times (V_y / V_x)$$

Units:

$$\Delta t = \text{seconds (s)}$$

$$t_0 = \text{seconds (s)}$$

$$V_y / V_x = \text{dimensionless}$$

5. Conclusion: From Geometry to Physics

By anchoring the Quantahedron lattice to the Compton wavelength of the electron and encoding observables through angular deviation, this model reinterprets physical constants as emergent from geometric constraint.

- **Mass** = deviation from symmetry
- **Energy** = propagation under constraint
- **Time** = delay induced by angular steepening

This framework supports simulation, experimental modeling, and deeper theoretical exploration by unifying geometry with measurable physics—validating that what we call mass, energy, and time may be **secondary expressions of form itself**.

(Wheeler, 1982; Penrose, 1967; Arkani-Hamed & Trnka, 2014)

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