

The Positron and the Cogwheel

Vacuum.Net as a Cellular Automaton in the Sense of 't Hooft

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Abstract

In October 2026 a group at Northwestern University reported the first one-positron quantum cyclotron: a single antielectron, held for months in a Penning trap, climbing and descending an evenly spaced ladder of quantum states one step at a time. This article asks a simple question about that ladder: what is it? Two answers are set side by side. The first is Gerard 't Hooft's. In his Cellular Automaton Interpretation of quantum mechanics, the world is a deterministic system of discrete states, and every finite, deterministic, time-reversible system decomposes into *cogwheels* — closed cycles of states. A cogwheel, written in quantum notation, produces exactly an evenly spaced ladder. The second answer is the Vacuum.Net theory, whose single axiom is that everything is a closed line. This article shows that the two answers coincide. The axiom of the net is the theorem of 't Hooft. The addresses of the net — rotation classes of balanced-ternary words — are his cogwheels, one for one. The local dynamics of the net's address layer, which has been shown to admit only the pure shift, is the cogwheel step itself. The positron experiment can then be read line by line in the language of loops. A worked example at depth three makes the identity concrete. Two points are then marked where the net goes further than 't Hooft (it needs no universal clock), and one point where both still have work to do: the rule by which loops couple.

1. A positron on a ladder

Take a single positron. Slow it down from the 546 keV it carries when it leaves a sodium-22 nucleus. Catch it in a Penning trap inside a 5.6 tesla magnetic field. Cool the trap to 300 millikelvin. Then watch.

This is what T. G. Myers, L. Soucy, B. A. D. Sukra, B. Sinha and G. Gabrielse did, and reported in *Physical Review Letters* on 21 October 2026. Their positron circles the magnetic field lines at about 156 GHz. It sits in the lowest cyclotron state. Apply a microwave drive near 156 GHz and it jumps one rung up. Wait, and it falls back. Drive harder and it climbs two rungs in quick succession, then falls back twice. Every rung is the same height. The levels follow the familiar formula

$$E = \hbar\omega_c (n + \frac{1}{2}), n = 0, 1, 2, \dots$$

on top of which sits a second, almost identical ladder for the spin. The spin precesses at $\omega_s = (g/2)\omega_c$. The two frequencies differ by only about one part in a thousand. Their difference, $\omega_a = \omega_s - \omega_c$, is called the anomaly frequency.

Several details of the apparatus will matter below.

- **Loading.** The positron does not enter the trap alone. Leaving a tungsten moderator, it pulls an electron from the surface. The two travel together as a loosely bound, neutral Rydberg positronium atom through a $640\ \mu\text{m}$ hole. Because the pair is neutral, the trap's electric field

does not see it. Only inside the trap is the field strong enough to pull the pair apart. The electron is lost; the positron is caught.

- **The cavity.** Without the surrounding electrodes, an excited cyclotron state would decay by radiation in about 83 milliseconds. The trap electrodes form a microwave cavity that suppresses this decay by up to a factor of two hundred. In this experiment the lifetime is about four seconds. That is long enough to see each rung.
- **The spin.** The spin is far more isolated. The calculated decay time of an upward spin is about 2.1 years. The lowest state with spin down does not decay at all.
- **Reading.** The cyclotron and spin states are not read directly. Nickel rings make a small magnetic bottle. This shifts the frequency of the positron's slow up-and-down motion along the field (about 206 MHz) by roughly 3.8 Hz per quantum. One loop is read through the frequency of another loop it is coupled to. The measurement does not change the state it reads.

The purpose of the work is precision. A one-electron quantum cyclotron in the same group measured the electron's magnetic moment to about one part in 10^{13} . The positron version should allow the same precision for antimatter. Comparing the two would test the symmetry between matter and antimatter in the lepton sector some thirty times more precisely than before.

The physics community will read this as a triumph of quantum electrodynamics. It is. But it also invites a more basic question. Quantum theory says the ladder is there. It does not say what the ladder *is*. Two answers to that question are the subject of this article.

2. 't Hooft: the world as cogwheels

Gerard 't Hooft, Nobel laureate in physics (1999) and professor at Utrecht, has argued for more than two decades that quantum mechanics is not the floor of reality. His fullest statement is *The Cellular Automaton Interpretation of Quantum Mechanics* (Springer, 2016; open access as arXiv:1405.1548). In it he treats quantum mechanics as a tool rather than a theory: a superb calculating device for a world that, underneath, is deterministic and discrete.

The construction is short.

Ontological states. There is a fixed set of states the world can actually be in. At any moment exactly one of them is realised. In quantum notation this means the only "real" wave function takes the value 1 on one basis state and 0 on all others.

Evolution. At each tick of the clock, the world moves from one ontological state to the next. Written as a matrix, this step contains only zeros and ones. It is a permutation. 't Hooft requires it to be invertible, so that no two states merge.

The cogwheel. The simplest such system has N states visited in a circle: $1 \rightarrow 2 \rightarrow \dots \rightarrow N \rightarrow 1$. 't Hooft calls this a cogwheel with N teeth. He then proves the key structural fact. Start anywhere in any finite, deterministic, time-reversible system and follow the evolution. After a finite number of steps you return to where you began. Start again from a state you have not yet visited, and you trace another closed cycle. Continue until every state is used. The result: *the most general finite, deterministic, time-reversible model is a collection of cogwheels*, each with its own number of teeth, all turning on the same tick.

From cogwheel to quantum ladder. Now apply a discrete Fourier transform to the N states of one cogwheel. The evolution operator becomes diagonal. Its logarithm defines a Hamiltonian whose eigenvalues are

$$E_k = 2\pi k / N, k = 0, 1, \dots, N - 1$$

in units of the tick. The levels are evenly spaced. In the continuum limit, with a small constant shift, the spectrum becomes $(2\pi/T)(k + \frac{1}{2})$: the spectrum of the harmonic oscillator. 't Hooft points out that the Zeeman splitting of an atom with angular momentum J is exactly the spectrum of a cogwheel with $2J + 1$ teeth. A Zeeman atom, seen in the right basis, is a cogwheel.

Superposition as a template. What then is a superposition? 't Hooft calls it a *template*. It is a state we write down when we do not know which ontological state the system is in. The squared amplitudes are the probabilities of each. Templates obey the Schrödinger equation, so they are indispensable for calculation. But they do not describe a state the world can be in. The dead cat is an ontological state. So is the live one. The superposed cat solves the equations but never occurs. On this reading the collapse of the wave function is not a physical process. It is an update of what we know.

The observer. Bell's theorem seems to forbid any local deterministic account of entangled particles. 't Hooft's answer is that Bell's argument silently assumes the experimenters can choose their settings independently of everything else in the universe. In a fully deterministic world the experimenters, their brains and their instruments obey the same laws as the particles. Their choices are not outside the system. This position is called superdeterminism.

What remains open for 't Hooft. He is candid about the gap. Free cogwheels are easy. Locally interacting particles are hard. When he builds models with interactions, the resulting Hamiltonian is often not both local and bounded from below. He does not yet have the cellular automaton for the Standard Model. He suggests gravity may be needed to close the gap.

3. The net: everything is a closed line

The Vacuum.Net theory starts from one idea. Everything is a closed line. A thing exists because it returns. Outside the path there is nothing; the observer is part of the path.

Three further elements are needed here.

Trits. The net is written in balanced ternary. Each position carries one of three values: $-1, 0, +1$. Balanced ternary needs no minus sign and no rounding rule. Negation is simply the exchange of $+$ and $-$. A trit is not an extra assumption added to the loop; it is how the balanced-ternary numbers read a position on it.

Addresses. An address in the net is a word of trits written on a ring. A ring has no first position. So an address is not a single word but a *rotation class*: the word together with all its cyclic shifts. In combinatorics such a class is called a necklace. The number of necklaces of length n over three symbols is

$$g(n) = (1/n) \sum_{d|n} \phi(n/d) \cdot 3^d,$$

which grows roughly as $3^n/n$. At depth 19 there are 61,171,659 of them.

Two layers. The net has two layers. The *address layer* is frozen topology: the closed loops that keep coming back. The *tension layer* is where anything happens: exchange, decay, change. Earlier work ("The Net Has No Hidden Clock", September 2026) checked exhaustively what the address layer can do. On a ring of five positions, every local rule (nearest neighbours only) that conserves the balance sum and lets every state return was enumerated: all $3^{13} = 1,594,323$ sign-symmetric rules

and all 144 conserving rules in flux form. The only survivors are the identity and the shift. In the address layer there is only passage. Change lives in the tension layer.

4. The identity

Put the two descriptions next to each other. Three statements follow almost at once.

4.1 The axiom is the theorem. The net's axiom says everything is a closed loop. 't Hooft's structural theorem says every finite, deterministic, reversible system is a set of closed cycles. 't Hooft reaches this as a consequence of determinism and finiteness. The net takes it as the ground. They state the same thing about the world.

4.2 An address is a cogwheel. Take one address: a necklace of trits on a ring of length n . One step of the loop moves the word one position along the ring. After a number of steps equal to the necklace's period d , the word is back where it began. That is exactly a cogwheel with d teeth. Every address of the net is one cogwheel. The catalogue of addresses at depth n is the list of cogwheels at depth n . The necklace count $g(n)$ counts cogwheels.

4.3 The address dynamics is the cogwheel step. The exhaustive result above says the only local, conserving, reversible dynamics on a single ring is the shift. The shift is the cogwheel step. So the address layer of the net is not merely *compatible* with 't Hooft's automaton. It *is* the pure cogwheel automaton, with nothing added.

4.4 What this gives for free. Because the address layer is a set of cogwheels, 't Hooft's machinery applies directly. Each address of period d carries an evenly spaced spectrum $2\pi k/d$. Energy is the number of full turns per tick: a frequency. The constant $\hbar$ enters only when frequencies are converted into joules. Quantum theory's evenly spaced ladders, its Zeeman levels and its oscillators, are what cogwheels look like in quantum notation. In the net they are what loops look like.

A further detail is worth noting. In his treatment of fermions, 't Hooft writes evolution operators whose entries are not only 0 and 1 but -1 , 0 and $+1$. These are balanced-ternary values. The trit is already present in his mathematics.

5. A worked example: depth three

Abstract identities convince less than a small case worked out in full. Take words of three trits. There are $3^3 = 27$ of them. Group them into rotation classes.

Class (representative)	Period (teeth)	Trit sum	Mirror partner
0 0 0	1	0	itself
+ + +	1	3	− − −
− − −	1	-3	+ + +
0 0 +	3	1	0 0 −
0 0 −	3	-1	0 0 +
+ + 0	3	2	− − 0
− − 0	3	-2	+ + 0

+ + -	3	1	- - +
- - +	3	-1	+ + -
0 + -	3	0	0 - +
0 - +	3	0	0 + -

There are eleven classes: three cogwheels with one tooth and eight with three teeth. Check: $3 \times 1 + 8 \times 3 = 27$. The formula agrees: $g(3) = (1/3)(3^3 + 2 \cdot 3) = 11$.

Now read off the spectrum. A one-tooth cogwheel has a single level, $E = 0$. A three-tooth cogwheel has three levels, $E = 0, 2\pi/3, 4\pi/3$. Over all 27 states:

Level (per tick)	Number of states
0	11
$2\pi/3$	8
$4\pi/3$	8

That is the complete "quantum" description of the net at depth three. It is a finite collection of loops, each turning on its own ring, each with its own small ladder. Note that the level spacing of the three-tooth cogwheels, $2\pi/3$, is exactly the phase step of one ternary position: one third of a full turn.

Three further features of the table matter for what follows.

Mirror pairs. Negating every trit maps each class to another class with the opposite trit sum. Negation does not interfere with rotation: shifting and then negating gives the same result as negating and then shifting. So a class and its mirror image have identical spectra. Mirroring changes the sign. It never changes the ladder.

Self-mirrored neutrality. The class 0 0 0 is its own mirror. The two classes 0 + - and 0 - + are each other's mirror; they are also each other's reversal (read the ring backwards). Mirror and reversal together map each of them onto itself.

Neutral words. Three classes carry trit sum 0: 0 0 0, 0 + -, 0 - +. They are loops that exist but carry no net sign.

6. The positron experiment, read as cogwheels

With the identity in place, the Northwestern experiment can be read line by line.

The cyclotron ladder is a cogwheel. The positron's orbit is a closed loop. Its quantum number n counts closures. The evenly spaced ladder $\hbar\omega_c(n + 1/2)$ is precisely the spectrum 't Hooft derives for the continuum limit of a cogwheel, including the half-step offset. The experiment shows, rung by rung, what a single cogwheel looks like when one tooth is excited at a time.

The spin is a second cogwheel, almost the same. Spin and orbit are two loops turning at nearly the same rate. Their frequency ratio is $g/2$, about 1.00116. They almost close together, but not quite. The anomaly frequency ω_a is the beat between two cogwheels whose tooth counts differ slightly.

What precision physics measures, to twelve or thirteen digits, is the ratio of two loops. That ratio is a pure number. It needs no constant of nature to be stated.

The positron is a mirror loop. To keep ω_c positive the authors orient their axis opposite to the magnetic field: the positron turns the other way round. In the net, antimatter is the mirrored address, every trit negated. Section 5 showed that negation commutes with the cogwheel step, so a mirrored address carries the same ladder. Read in the address layer, the net therefore gives electron and positron exactly the same spectrum, and so exactly the same magnetic moment. The comparison the Northwestern group is preparing tests precisely this.

Loading through a zero. The positron enters the trap bound to an electron. The pair is neutral: +1 and -1 together make 0. The trap's field does not act on it. Only inside the trap does the pair split, and only then does charge appear. This is the net's neutral word made visible in the laboratory: a loop with sum zero passes where a signed loop would be stopped.

The cavity is context. An excited cyclotron state decays by radiating into the electromagnetic field. In the language of loops, decay is an exchange between the positron's cogwheel and cogwheels of the surrounding field. That exchange belongs to the tension layer. The cavity removes the field's partner loops near 156 GHz, and so the exchange is suppressed: 83 milliseconds becomes four seconds. The decay rate is not a property of the positron alone. It is a property of the positron together with its surroundings. In the net this is not a surprise. Context belongs to the path.

The spin is frozen. The spin barely exchanges with anything. Its calculated lifetime is about two years, and the lowest state with spin down does not decay at all. The spin behaves like the address layer: frozen, passing, unchanged. The orbit behaves like the tension layer: it exchanges, rises and falls. The two-layer structure of the net is visible in a single particle.

Reading through another loop. The cyclotron and spin states are read by the shift they cause in the frequency of a third loop, the slow axial oscillation, about 3.8 Hz per quantum. No instrument stands outside. One loop is read through the count of another loop coupled to it. This is what the net means by saying the observer is part of the path. It is also what 't Hooft means when he refuses to place the experimenter outside the deterministic system.

7. Where the net goes further

The identity is close, but not complete. In two respects the net needs less than 't Hooft's automaton.

No universal clock. 't Hooft's cogwheels all turn on one common tick, which he places near the Planck time. All of them share it. The net has no such clock. Time in the net is the counting of turns of the loop itself; each address returns on its own period. 't Hooft's own mathematics already points this way. He notes that each cogwheel's energy can be shifted by its own arbitrary constant without any physical effect, because which cogwheel a state belongs to never changes. Each cogwheel is, in that sense, its own clock. The net simply takes this seriously and drops the common tick.

No prior lattice. 't Hooft places his automaton on a lattice given in advance, a grid of sites in space. The net has no grid. The net is the path the movement traces. Addresses are not positions on a pre-existing structure; they are the structure. Where 't Hooft must eventually explain why his lattice has the geometry it has, the net does not carry that burden.

Superposition. On 't Hooft's reading a superposition is a template, not a state of the world. The net arrives at the same place from its own starting point. Outside the path there is nothing. An address is therefore either traced or not traced: 1 or 0. A weighted mixture of addresses is a statement about

what we know, not a configuration of the net. Probabilities measure ignorance of which loop is being traced.

8. What both still have to write

There is one place where neither 't Hooft nor the net is finished, and it is the same place.

Free cogwheels are simple. The world, however, is full of exchange: emission, absorption, scattering, chemistry, life. In 't Hooft's account this is the problem of constructing a cellular automaton with local interactions whose quantum Hamiltonian is both local and bounded from below. He states openly that he has not yet found it for realistic particles.

In the net this is the tension layer. The address layer has been shown to allow only passage. All change must therefore come from the rule by which loops exchange trits with one another while the total balance stays conserved. The exhaustive result of Section 3 adds a constraint of its own: this rule cannot live inside a single ring with nearest-neighbour steps. It must act between rings, or reach further along them.

The cavity in the positron experiment shows what such a rule must do. It must let the cyclotron loop give up a tooth to the field. It must make that exchange depend on which partner loops are present. And it must leave the spin loop almost untouched. Writing that coupling rule explicitly, in balanced ternary, between rings, is the next piece of work. It would complete the automaton in the place where 't Hooft's remains open.

9. Conclusion

A single positron on a ladder looks like the purest quantum object there is. Read with 't Hooft, it is a cogwheel: a closed cycle of states that quantum notation renders as evenly spaced levels. Read with the Vacuum.Net theory, it is a loop: a thing that exists because it keeps coming back. These are not two readings. They are one.

The net's single axiom — everything is a closed line — is 't Hooft's structural theorem. The net's addresses are his cogwheels. The net's address dynamics is his cogwheel step, and nothing else. The positron experiment, in its loading, its cavity, its frozen spin and its indirect reading, shows the two layers of the net working in one particle. The comparison of electron and positron that the experiment now makes possible tests a symmetry the net carries in its arithmetic: negating the trits changes the sign, never the ladder.

Quantum mechanics, on this view, is what loops look like when you calculate with them. The loops themselves are what there is.

Annotated references

The experiment

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positronium loading through a $640\text{ }\mu\text{m}$ hole, cavity-inhibited decay (83 ms to $\sim 4\text{ s}$), spin lifetime $\sim 2.1\text{ yr}$, quantum non-demolition reading via the axial frequency.

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The cellular automaton

- **G. 't Hooft, *The Cellular Automaton Interpretation of Quantum Mechanics, Fundamental Theories of Physics* 185 (Springer, 2016); arXiv:1405.1548.** Open access. Chapter 2 gives the cogwheel model, its evenly spaced spectrum and the theorem that every finite deterministic reversible model is a set of cogwheels (Section 2.2.2). Chapter 13 gives the continuum limit and the harmonic oscillator. Chapter 15 uses evolution operators with entries $-1, 0, +1$. Chapters 3–5 treat templates, the Born rule and superdeterminism; Chapters 8–9 state the open problems with interactions.
- **A. Einstein, B. Podolsky, N. Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Phys. Rev.* 47, 777 (1935).** The classic statement that quantum theory does not describe what is. 't Hooft places his work in this line.
- **J. S. Bell, "On the Einstein Podolsky Rosen Paradox," *Physics* 1, 195 (1964).** The theorem 't Hooft answers with superdeterminism, and which the net answers by placing the observer on the path.
- **E. Fredkin, "Digital Mechanics," *Physica D* 45, 254 (1990).** An early programme for a discrete, deterministic physics; acknowledged by 't Hooft as a direct influence.

The net

- **J. Konstapel, "The Vacuum.Net Theory: Foundational Paper" (Leiden, 2026), [constable.blog](#).** The axioms of the net, the role of closure, the double cover and the quaternionic ground.
- **J. Konstapel, "Everything Has Its Number in the Maze" (Leiden, 2026), [constable.blog](#).** The balanced-ternary ground of the net and the address theorem; why three values and why no minus sign.
- **J. Konstapel, "The Net Has No Hidden Clock" (Leiden, September 2026), [constable.blog](#).** The exhaustive check that on the ring only the identity and the shift survive as local, conserving, reversible rules. The basis of Sections 3 and 4.3.
- **J. Konstapel, "The Current State of the Vacuum.Net Theory" (Leiden, 3 September 2026), [constable.blog](#).** The two-layer law (address layer and tension layer) used throughout Sections 3, 6 and 8.
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