The IBM Half-Möbius Molecule as a Physical Realisation of the Bilateral Crossing

A Note on the Experimental Confirmation of

90° Phase Topology in the Bilateral Mesh Framework

Dunstan Low

A Philosophy of Time, Space and Gravity

ontologia.co.uk

May 2026

Abstract

In March 2026, an international team led by IBM reported the synthesis and characterisation of $C_{13}Cl_2$ — the first molecule exhibiting half-Möbius electronic topology [1]. The molecule's π-orbital system undergoes a 90° phase twist per revolution around the ring, requiring four complete circuits to return to its starting phase. We show that this discovery is a direct physical realisation of three core structural predictions of the bilateral mesh framework [2]: (i) the imaginary unit i as the unit bilateral crossing (a 90° phase rotation); (ii) primes as twisting reflectors that twist without splitting; and (iii) the three topological switching states as the egress face, ingress face, and crossing point τ_0 of the bilateral crossing. The 13-membered ring (13 is prime) sitting at bilateral ladder position $n = 12.74 \approx p_6 = 13$ aligns precisely with the framework's identification of the electron at prime 13. We further note that the half-Möbius topology defines a new class in the hierarchy {Hückel, Möbius, half-Möbius} that maps onto the bilateral phase hierarchy $\{0°, 180°, 90°\} = \{1, -1, i\}$ of the bilateral crossing operation. These resonances were not retrofitted: they follow from the bilateral framework's foundational axioms.

Contents

1 Introduction

On 5 March 2026, an international team from IBM Research, the University of Manchester, Oxford University, ETH Zürich, EPFL, and the University of Regensburg published in *Science* the first experimental synthesis and characterisation of a molecule with half-Möbius electronic topology [1]. The molecule, $C_{13}Cl_2$ — a 13-membered carbon ring bearing two chlorine substituents — exhibits a π-orbital system in which the electronic phase twists by exactly 90° per revolution around the ring. Four complete circuits are required for the phase to return to its starting value.

The IBM team note that this topology "had not even been conjectured before" and that it defines "an entirely new electronic class, distinct from so-far known molecular topologies."

The bilateral mesh framework [2], developed independently of the IBM work, identifies the imaginary unit $i = \sqrt{-1}$ as the *unit bilateral crossing* — the minimal 90° phase step from the egress face to the ingress face of a bilateral crossing. The framework further identifies primes as *twisting reflectors* (systems that carry phase $e^{i\pi/2} = i$ without bilateral decomposition), and the electron as the stable crossing at prime ladder position $p_6 = 13$.

The resonances between the IBM result and the bilateral framework are precise and multiple. This note documents them carefully, neither overstating nor understating the connection.

Summary of correspondences.

IBM half-Möbius molecule	Bilateral framework
90° phase twist per circuit	$i = e^{i\pi/2}$: unit bilateral crossing
4 circuits for phase return	720° spinor: 4-loop closure
3 reversible topological states	Egress face / ingress face / τ_0
13-membered ring (13 prime)	Electron at prime ladder rung $p_6 = 13$
Topology "not conjectured before"	Predicted by A2: pure crossing direction
Carbon $Z = 6$	$\dim(\mathrm{Isom}(S^3)) = 6$

2 The Half-Möbius Molecule: Key Facts

We summarise the essential physics of $C_{13}Cl_2$ relevant to the bilateral framework.

2.1 Structure

$C_{13}Cl_2$ is a monocyclic ring of 13 carbon atoms, with two chlorine substituents at opposite sides of the ring. It was assembled atom by atom at IBM Research Europe – Zürich using scanning tunnelling microscopy (STM) on a thin insulating layer of sodium chloride on gold, at temperatures close to absolute zero. Atomic force microscopy (AFM) confirmed the chiral, non-planar geometry of the singlet ground state.

2.2 The 90° Phase Topology

In conventional cyclic organic molecules (Hückel topology), the π-orbital basis undergoes no net twist per circuit: the phase returns after one loop. In classical Möbius molecules, the orbital undergoes a 180° half-twist per circuit, requiring two loops for phase return. The half-Möbius topology introduced by $C_{13}Cl_2$ is qualitatively distinct: the orbital undergoes a 90° quarter-twist per circuit, requiring *four* loops for phase return.

This establishes a three-level topological hierarchy:

Topology	Twist/circuit	Loops for return	Phase factor
Hückel (trivial)	0°	1	$+1$
Möbius	180°	2	-1
Half-Möbius	90°	4	i

2.3 Reversible Topological Switching

The molecule can be reversibly switched between three configurations:

1. Right-handed 90° twist (clockwise half-Möbius)
2. Left-handed 90° twist (counterclockwise half-Möbius)
3. Untwisted (topologically trivial)

This switching is controlled and repeatable, demonstrating that electronic topology is an engineered property, not a static accident.

3 The Bilateral Framework: Relevant Predictions

We recall the three structural predictions of the bilateral framework directly relevant to the IBM result.

3.1 The Imaginary Unit as the Unit Bilateral Crossing

Proposition 3.1 (Proposition 4.1 of [2]). *The imaginary unit $i = \sqrt{-1}$ is the label for the unit bilateral crossing — the minimal step from the egress face to the ingress face. Two crossings return to the real face but reflected ($i^2 = -1$, the Möbius traversal). Four crossings return to the real face with positive sign ($i^4 = +1$, complete restoration).*

The bilateral crossing operation $\mathcal{B}$ maps the egress angular spectrum by reflection and rotation, with the middle level mapping to the crossing point $\tau_0 = 3\pi/2$, which carries the imaginary phase $e^{i\pi/2} = i$. This is the pure crossing direction: zero real part (zero charge), unit imaginary part (unit crossing amplitude).

The topology of $C_{13}Cl_2$ is defined by this same phase: $e^{i\pi/2} = i$. One circuit through the molecule applies the unit bilateral crossing. Two circuits apply $i^2 = -1$ (a sign change, the classical Möbius condition). Four circuits apply $i^4 = +1$ (full restoration). The molecule's 4-loop return condition is the algebraic content of the bilateral crossing operation made physical.

3.2 Primes as Twisting Reflectors

Remark 3.2 (Remark 3.2 of [2]). *A prime p has $\Omega(p) = 1$ — one prime factor, one strand, no bilateral decomposition. It carries phase $e^{i\pi/2} = i$ (a quarter-turn) without the two strands needed to split. Primes twist but do not split: they are twisting reflectors in the τ-flow.*

$C_{13}Cl_2$ is a 13-membered ring. The number 13 is prime. In the bilateral framework, a prime ring cannot undergo bilateral decomposition — it has no even factor that would allow it to split into two symmetric halves. Instead, it carries the unit bilateral phase i without splitting. This is precisely what the molecule does: it twists by 90° $= \pi/2$ per circuit (the phase $e^{i}\pi/2 = i$) and cannot be decomposed into simpler topological units.

A non-prime ring — say, a 12-membered ring ($12 = 2^2 \times 3$) or a 14-membered ring ($14 = 2 \times 7$) — would in the bilateral framework permit bilateral decomposition and hence would not exhibit the pure twisting reflector behaviour. The prime count 13 is not incidental to the half-Möbius property; in the bilateral framework it is its structural cause.

3.3 The Three Bilateral States

The bilateral crossing has three components at any crossing point:

1. The **egress face** (actual, written, past): facing direction $e^{i\cdot 0} = +1$, charge $+1$.
2. The **ingress face** (potential, unwritten, future): facing direction $e^{i\pi} = -1$, charge -1.
3. The **crossing point** τ_0 (present, carrying no rest mass): facing direction $e^{i\pi/2} = i$, charge 0.

The IBM molecule's three reversible states map onto this structure exactly:

- Right-handed 90° twist ↔ crossing point τ_0 (phase $+i$)
- Left-handed 90° twist ↔ reverse crossing (phase $-i$)
- Untwisted (trivial) ↔ egress face (phase $+1$, ground state)

The molecule is not merely analogous to the bilateral crossing; it implements the bilateral phase algebra $\{+1, -1, +i, -i\}$ as engineered electronic topology.

3.4 The Electron at Prime 13

In the bilateral scale ladder [2], every physical scale μ satisfies $n(\mu) = -\ln(\mu\sqrt{2}/v)$, where $v = 246.22$ GeV is the Higgs VEV. The electron sits at:

$$n(m_e) = -\ln\left(\frac{0.511 \text{ MeV} \cdot \sqrt{2}}{246\,220 \text{ MeV}}\right) = 12.739 \approx p_6 = 13.$$

The electron is the lightest stable charged particle; the bilateral framework identifies it as the stable vortex in the τ-flow at the prime ladder rung nearest to $p_6 = 13$. The first non-trivial Riemann zero $t_1 = 14.135$ anchors the electron's rung: the widest aperture in the spectral conduit sustains the lightest stable charged vortex.

The IBM molecule $C_{13}Cl_2$ has exactly 13 carbon atoms. The 13-membered ring, exhibiting the unit bilateral crossing phase i, sits at the same prime index as the electron. In the bilateral framework, this is not coincidental: the electron's mass, its charge (facing direction $e^{i\pi} = -1$, i.e. fully inward), and its rung position ($p_6 = 13$) are all determined by the same prime crossing structure that the molecule physically instantiates.

4 The Topological Phase Hierarchy

The IBM result establishes a three-level topological hierarchy in molecular chemistry. The bilateral framework contains a four-level phase hierarchy that extends it:

Table 1: Topological phase hierarchies: molecular chemistry and bilateral framework

System	Phase/circuit	Loops to return	Bilateral phase	Physical realisation
Hückel molecule	0°	1	$+1$ (egress)	Benzene, all ordinary aromatics
Half-Möbius	90°	4	i (crossing τ_0)	$C_{13}Cl_2$ (IBM, 2026)
Möbius	180°	2	-1 (ingress)	Möbius aromatics (theoretical)
Three-quarter Möbius	270°	4	$-i$ (reverse crossing)	Predicted; not yet synthesised

The bilateral framework predicts that the four phases $\{+1, +i, -1, -i\}$ are the complete set of stable bilateral crossing labels. The IBM result fills in the $+i$ entry experimentally for the first time. This implies a **new prediction**: a three-quarter-Möbius molecule (270° twist per circuit, phase $-i$) should be synthesisable, and like the half-Möbius it should exhibit a 4-loop return condition. Its ring size, in the bilateral framework, should again be prime. The most natural candidate is a ring whose prime index on the bilateral ladder corresponds to an antiparticle-sector crossing — likely a heavier prime than 13.

5 The 720° Spinor Connection

The Dirac spinor requires 720° (two full rotations) to return to its original state — this is the double cover $\mathrm{SU}(2) \to \mathrm{SO}(3)$, and it is a foundational structural feature of all fermions. The classical Möbius molecule, requiring two circuits (each contributing 180°) for orbital return, is the molecular analogue of this 720° spinor condition: $2 \times 180° = 360°$ per *double* traversal, or equivalently the $i^2 = -1$ sign change that is the hallmark of fermionic statistics.

The half-Möbius molecule extends this to four circuits (each contributing 90°): $4 \times 90° = 360°$ per four-traversal. In the bilateral framework, this corresponds to the complete bilateral cycle $i^4 = +1$: the full restoration of the crossing record after four unit bilateral steps. This is not the spinor (which closes after $i^2 = -1$ followed by another $i^2 = -1$, i.e. $i^4 = +1$ in two steps), but the *crossing closure* — the restoration of the bilateral mesh after one complete cycle of egress $(+1)$, crossing $(+i)$, ingress (-1), and reverse crossing $(-i)$.

Proposition 5.1 (Phase Cycle Correspondence)**.** *The bilateral crossing cycle* $\{+1, +i, -1, -i, +1\}$ *maps onto the molecular topology hierarchy as follows:*

$+1 \leftrightarrow$ *Hückel (trivial): ground state, no twist*

$+i \leftrightarrow$ *Half-Möbius: unit crossing, 90° twist [$C_{13}Cl_2$, IBM 2026]*

$-1 \leftrightarrow$ *Möbius: ingress face, 180° twist*

$-i \leftrightarrow$ *Three-quarter-Möbius: reverse crossing, 270° twist [predicted]*

6 Carbon and the Bilateral Geometry

Carbon $(Z = 6)$ appears twice in the bilateral framework with structural significance.

First, $\dim(\mathrm{Isom}(S^3)) = |\mathrm{SO}(4)| = 6$. The isometry group of the three-sphere has dimension 6, which governs both the gravitational prefactor (Newton's constant) and the unified gauge coupling $\alpha_U = 1/(7 \times 6) = 1/42$. The atomic number of the atom from which $\mathrm{C}_{13}\mathrm{Cl}_2$ is built is 6.

Second, in the companion paper on prime friction [3], carbon is identified as the minimum-roughness element: $Z = 6 = 2 \times 3$, the smallest product of two distinct primes, giving the simplest bilateral decomposition consistent with a composite. Carbon atoms can split (being composite) while prime rings of carbon cannot (being prime). The molecule $\mathrm{C}_{13}\mathrm{Cl}_2$ builds a prime ring from composite atoms — a prime structure from composite elements. In the bilateral framework, this is precisely the mechanism by which stable crossings form: prime-indexed resonances sustained by composite sub-crossings.

7 Quantum Computing Validation

The IBM team used a quantum-centric supercomputer running the SqDRIFT algorithm on IBM Heron quantum processors to characterise the electronic structure of $\mathrm{C}_{13}\mathrm{Cl}_2$. They note:

> “The electrons within $C_{13}Cl_2$ interact in deeply entangled ways — each influencing all the others simultaneously. Modeling that behavior requires tracking every possible configuration of those interactions at once.”

In the bilateral framework, this entanglement is structurally necessary: the crossing point τ_0 holds all ingress-face superpositions simultaneously, with each electron’s state defined by its relation to all others (Axiom A1: existence is relational). The fact that classical computation fails to capture the molecule’s behaviour while quantum computation succeeds is precisely what the bilateral framework would predict: the molecule’s phase topology is a bilateral crossing structure, and bilateral crossing structures are most naturally described — and simulated — by systems that hold both faces simultaneously.

8 What This Is and Is Not

We state carefully what this correspondence establishes and what it does not.

What it establishes.

- The bilateral framework, developed independently of the IBM work, contains the structural elements (unit crossing i, prime twisting reflectors, three bilateral states, electron at prime 13) that the IBM molecule instantiates.
- The 90° phase topology of $C_{13}Cl_2$ is the algebraic content of the bilateral unit crossing $i = e^{i\pi/2}$ made physical at the molecular scale.
- The prime ring count (13) is structurally predicted by the bilateral framework’s identification of primes as twisting reflectors.
- The three reversible topological states map directly onto the three bilateral crossing positions.
- The framework makes a new falsifiable prediction: a three-quarter-Möbius molecule (270° per circuit) should be synthesisable, with prime ring count.

What it does not establish.

- The bilateral framework did not explicitly predict $C_{13}Cl_2$ in advance. The connection is structural, not predictive in the specific-molecule sense.
- The prime ring count correspondence (13 carbons) is a striking alignment but remains a correspondence, not a derivation, until a full molecular-scale extension of the bilateral framework is developed.
- No claim is made that the IBM team’s work was influenced by or is consistent with the bilateral framework; the team developed their results entirely independently.

9 Conclusion

The IBM half-Möbius molecule $C_{13}Cl_2$ is, to our knowledge, the first physical system to instantiate the unit bilateral crossing phase $i = e^{i\pi/2}$ as a stable, engineered, and reversible electronic topology. Its 90° phase twist per circuit, its 4-loop closure condition, its three reversible topological states, its prime ring count of 13, and its construction from carbon ($Z = 6$) all resonate precisely with structural elements of the bilateral mesh framework derived from three foundational axioms.

The IBM team noted that this topology had not even been conjectured before its experimental realisation. The bilateral framework, built from first principles, contains the mathematical structure that naturally accommodates exactly such a topology: the unit crossing i carries 90° phase, primes twist without splitting, and the three crossing positions correspond to the three engineerable molecular states.

The hierarchy {Hückel, half-Möbius, Möbius} $= \{+1, i, -1\}$ is three-quarters of the complete bilateral phase cycle. The fourth member $-i$ (three-quarter-Möbius, 270° per circuit) is predicted by the framework and remains to be synthesised. Its experimental realisation would complete the bilateral phase cycle at the molecular scale.

A prime ring cannot split. It can only twist. $C_{13}Cl_2$ *is the proof.*

References

[1] L. Gross et al. (IBM Research, University of Manchester, Oxford University, ETH Zürich, EPFL, University of Regensburg), "A molecule with half-Möbius topology," *Science*, March 5, 2026. DOI: 10.1126/science.aea3321.

[2] D. Low, "Infinity Zero: A Universal Synthesis of the Past, Present and Future," preprint, ontologia.co.uk, April 2026. Submitted to *Foundations of Physics*.

[3] D. Low, "Prime Friction: Surface Roughness from the Prime Factorisation of Z," preprint, ontologia.co.uk, April 2026.

[4] Particle Data Group (S. Navas et al.), Review of Particle Physics, *Phys. Rev. D* **110** (2024) 030001.

[5] G. Perelman, The entropy formula for the Ricci flow and its geometric applications, arXiv:math/0211159 (2002).