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Persistent Chiral Step-Defect of the Chrysene Lattice: Homochirality of Amino Acids, Sugars, and Membrane Lipids, and Consistency with the Meteoritic Record

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Abstract

Biological homochirality—L-amino acids, D-sugars, and the specific stereochemistry of membrane lipids—remains unexplained by unconstrained stochastic chemistry. Carbonaceous chondrites preserve the only known pre-terrestrial enantiomeric excesses of matching sense (L-excesses in α-methyl amino acids, D-excesses in aldonic acids) together with indigenous chrysene-family polycyclic aromatic hydrocarbons.

Under the Identification Hypothesis the tetrasubstituted chrysene lattice carries a native chiral step-defect. Patent US 12,195,423 already maps this defect into paired nucleobases and, via the catalyst chrysene, into the membrane component. The same defect, constrained by the C12 tether geometry of the dual-cage synthesis, produces a statistical excess of L-amino acids. Controlled bay scission generates a void complementary to D-fructose; the stereochemistry fixed at this stage is retained through the glycolytic metabolon into glucose and related sugars. The identical stereochemical packet persists from the dual-chrysene catalyst through hopanoids and sterols into membrane-bound cholesterol.

A single geometric object therefore accounts for the handedness of the three major biopolymer classes and is consistent with the meteoritic record in which the chrysene skeleton and the enantiomeric excesses of biological sense coexist. Homochirality is framed as the biological amplification of a persistent lattice bias that was already available in the prebiotic and extraterrestrial organic inventory.

Keywords: Chrysene Formalism; chiral step-defect; homochirality; L-amino acids; D-sugars; ghost pocket; meteoritic enantiomeric excess; hopanoid–sterol stereochemistry; cholesterol; Patent US 12,195,423

1 Introduction

1.1 Empirical Problem Statement

Terrestrial biology is constructed almost exclusively from L-amino acids and D-sugars, and its membrane lipids exhibit characteristic absolute configurations that are preserved in the geological hopane and sterane records. This universal handedness is not explained by the statistics of unconstrained aqueous chemistry.

Carbonaceous chondrites supply the sole pre-terrestrial benchmark: L-enantiomeric excesses in non-protein α-methyl amino acids (typically 2–18 %) and D-enantiomeric excesses in aldonic acids (frequently 30–55 %), accompanied by indigenous four-ring polycyclic aromatic hydrocarbons that include chrysene. Related PAHs are present in the interstellar medium and in returned asteroidal samples.

These observations raise a precise geometric question: does there exist a single, persistent structural feature that can account for the observed biases across informational polymers, membrane lipids, amino acids and sugars, and that is consistent with the co-occurrence of the chrysene skeleton and the enantiomeric excesses in the meteoritic record?

1.2 Chrysene Formalism Prediction

Under the Identification Hypothesis the pure-mathematical manifold $\mathcal{I}_C$ is realised by the physical chrysene lattice. The tetrasubstituted chrysene unit carries a native chiral step-defect (bay-region geometry).

Patent US 12,195,423 maps this defect into the geometry of paired nucleobases and, through the catalyst chrysene of the dual-cage volume, into the membrane component. The refined

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geometric claims of the present work are:

1. the C12-tether geometry of the dual-cage synthesis, bounded by the step-defect and neighbouring π-stacked units, produces a statistical excess of L-amino acids that is subsequently encoded into protein;
2. controlled bay scission generates a void complementary to D-fructose; because phosphofructokinase operates inside a metabolon, the stereochemistry fixed at this stage propagates to glucose and the downstream sugars of central metabolism;
3. the identical stereochemical packet persists from the dual-chrysene catalyst through hopanoids and sterols into membrane-bound cholesterol.

1.3 Central Claim and Roadmap

Claim 1. *The chiral step-defect of the tetrasubstituted chrysene lattice is a single geometric object that accounts for the handedness of nucleic acids (by patent mapping), membrane lipids,* L*-amino acids and* D*-sugars, and that is consistent with the meteoritic record in which the chrysene-family skeleton and the enantiomeric excesses of biological sense coexist.*

The argument proceeds in four stages. First, the empirical boundary conditions furnished by the meteoritic, lipid and interstellar records are fixed without theoretical interpretation. Second, the step-defect and the two new pocket geometries (amino-acid and sugar) are formalised. Third, these geometric predictions are confronted with the observational constraints. Fourth, a set of concrete, testable consequences and open experimental targets is recorded.

2 Empirical Framework – Data Constraints

The geometric constructions of subsequent sections are required to be consistent with the following observational boundary conditions. No theoretical interpretation is advanced in the present section; the data are recorded solely as empirical constraints.

2.1 Present-Day Biological Chirality as Boundary Condition

Before the geometric constructions are introduced, the universal stereochemical facts of contemporary biology are recorded as an independent empirical boundary condition. These facts are not derived from the Chrysene Formalism; they are the present-day observables that any successful geometric account must ultimately recover.

1. **Amino acids.** The twenty proteinogenic amino acids (with the exception of the achiral glycine) occur in biological polypeptides almost exclusively as the L-enantiomers. This preference is universal across the bacterial, archaeal and eukaryotic domains.
2. **Sugars.** The principal monosaccharides of central metabolism, most notably D-glucose and D-fructose, together with the ribose and deoxyribose of nucleic acids, belong to the D-series. The same D-configuration is retained through the glycolytic and gluconeogenic pathways.
3. **Membrane lipids.** Biological hopanoids and sterols exhibit characteristic absolute configurations at defined ring junctions and side-chain centres. In eukaryotic membranes the sterol scaffold continues as cholesterol (and related sterols), preserving the same stereochemical packet that is recorded in the geological hopane and sterane record.
4. **Informational polymers.** The backbone geometry of DNA and RNA, and the complementary pairing of the nucleobases, incorporate a chiral architecture that is already mapped, in Patent US 12,195,423, onto the step-defect of the tetrasubstituted chrysene lattice.

Collectively these four regularities constitute the present-day biological boundary condition: a single organism simultaneously maintains L-amino acids in its proteins, D-sugars in its metabolism and nucleic acids, a defined stereochemistry in its membrane lipids, and a chiral architecture in its genetic material. Any geometric model that accounts for only one of these biases while leaving the others unexplained is incomplete with respect to the living system that actually exists.

The remainder of this section shows that the chiral step-defect of the chrysene lattice, together with the C12-tether and scission-generated void geometries already introduced, recovers all four biases from one and the same structural object.

2.2 Meteoritic Enantiomeric Excesses

Carbonaceous chondrites preserve the only known pre-terrestrial record of molecular chirality. The following regularities are established by enantioselective chromatography and isotopic analysis of interior samples:

1. **Amino-acid excesses.** Non-protein α-methyl amino acids, most notably isovaline, exhibit L-enantiomeric excesses typically in the range 2–18 %. Higher values (up to approximately 18 %) are reported for isovaline in the more aqueously altered CM and CI lithologies (Murchison, Orgueil). Isotopic compositions (δ^{13}C, δ^{15}N, δD) of the individual enantiomers support an extraterrestrial origin for at least a substantial fraction of the measured excess.
2. **Sugar-acid excesses.** Several aldonic acids (threonic, erythronic and higher homologues) display D-enantiomeric

excesses, frequently in the range 30–55 %. The smallest sugar acid, glyceric acid, is generally racemic or nearly so; the magnitude of the D-excess tends to increase with carbon number. Distributional and isotopic arguments again favour an indigenous, non-terrestrial source for the observed excesses.

Collectively these data establish that the same meteoritic organic inventory carries both an L-bias in the amino-acid series and a D-bias in the sugar-acid series—the identical sense of handedness later adopted by terrestrial biology.

2.3 Chrysene and Related Polycyclic Aromatic Hydrocarbons in Meteoritic and Interstellar Material

Polycyclic aromatic hydrocarbons (PAHs) are indigenous constituents of carbonaceous chondrites. Four-ring species, including chrysene itself in multiple independent analyses, have been identified in Murchison, Murray, Orgueil and related meteorites. Related PAHs are widespread in the interstellar medium and have been detected in returned samples from the asteroids Ryugu and Bennu.

The co-occurrence, within the same extraterrestrial organic repertoire, of the chrysene-family skeleton and of the enantiomeric excesses recorded above constitutes an empirical boundary condition of particular relevance to any geometric model that invokes a chrysene-derived chiral bias.

2.4 Biological and Geological Lipid Stereochemistry

1. **Hopanoids and sterols.** Biological hopanoids and sterols exhibit characteristic absolute configurations at defined ring junctions and side-chain centres. These configurations are preserved, after diagenetic alteration, in the corresponding hopane and sterane biomarkers of the sedimentary record.

2. **Persistence into membrane-bound cholesterol.** The sterol scaffold continues into contemporary eukaryotic membranes as cholesterol and related sterols. The stereochemical packet of the membrane lipid therefore constitutes a continuous geological-to-biological thread.

2.5 Scope Limitation

The mapping of the chrysene step-defect onto paired nucleobases is taken as already established by Patent US 12,195,423 and is cited only; no new conformational analysis of DNA or RNA is undertaken. Stereochemical questions concerning α-helices, β-sheets, and the broader abiotic-loom architecture are reserved for subsequent work on metabolons and catalytic voids.

These empirical constraints—meteoritic enantiomeric excesses of matching biological sense, the presence of the chrysene skeleton in the same extraterrestrial inventory, and the continuous stereochemistry of membrane lipids—are fixed before any geometric model is introduced.

3 Geometric Model of the Persistent Step-Defect and Chiral Pockets

Throughout this section the Identification Hypothesis is assumed. All constructions are therefore understood as images under the structure-preserving map Φ of the corresponding structures of the pure-mathematical manifold $\mathcal{I}_C$.

3.1 Definition of the Chiral Step-Defect

Definition 1 (Chiral Step-Defect)**.** *Let c be an elementary tetrasubstituted chrysene component of native C_{2h} symmetry. The bay-region geometry of c constitutes a chiral step-defect: a non-superimposable structural bias fixed by the relative disposition of the fused rings and the substitution loci. The defect is an intrinsic geometric property of the lattice and is independent of any external radiation field.*

3.2 Transmission into the Membrane Lineage

Proposition 1 (Membrane Continuity of the Step-Defect)**.** *In the dual-chrysene reactive volume the catalyst unit carries the step-defect of Definition 1 into the membrane-component product. The resulting stereochemical packet is inherited by hopanoids and by sterols, and persists into membrane-bound cholesterol. Consequently the same geometric bias that the patent maps into the informational product is continuously expressed in the membrane lineage from the moment of integrated synthesis through the geological sterane record to contemporary eukaryotic membranes.*

3.3 L-Amino-Acid Bias from the Patent Synthesis Geometry

Proposition 2 (Lattice-Constrained L-Amino-Acid Excess)**.** *The chirality of the amino-acid series is a direct geometric consequence of the DNA/RNA–phospholipid integrated synthesis formalised in Patent US 12,195,423.*

1. *Within the dual-chrysene reactive volume the CCA complex is assembled while a single residual tether remains at the* C12 *position.*

2. *The spatial relationship of this* C12 *tether to the chiral step-defect, further bounded by the neighbouring π-stacked chrysene units, fixes the orientation of the nascent backbone and the relative placement of the*

side-chain.

3. *Under these constrained lattice conditions the geometry preferentially yields the* L*-series amino acid.*
4. *In an unconstrained environment the same chiral bay is competent to generate both* D- *and* L*-enantiomers; the lattice constraint therefore produces a mixture that carries a statistical excess of the* L*-enantiomer.*
5. *Once formed, this* L*-excess is encoded into subsequent protein synthesis, transmitting the lattice bias into the polypeptide product.*

The lattice constraint does not render the bay absolutely stereospecific; it converts a potentially racemic output into a statistical excess of the L*-enantiomer.*

Proof of Proposition 2. Let c be a tetrasubstituted chrysene unit carrying the chiral step-defect of Definition 1, and let the residual tether be fixed at the C12 locus. The neighbouring π-stacked units impose a hard steric boundary that restricts the dihedral freedom of the tether to a single open half-space relative to the bay-region plane.
Within this restricted half-space the nascent backbone can approach the step-defect from only one facial direction. The relative placement of the side-chain is thereby fixed by the same boundary: the side-chain is forced into the sterically allowed quadrant that corresponds to the L-configuration at the α-carbon.
In the absence of the lattice boundary both facial approaches remain open, and both D- and L-configurations are generated with equal measure. The imposition of the π-stack boundary removes one of the two measure-theoretic components, leaving a residual statistical excess of the L-enantiomer.
Once the L-amino acid is released from the dual-cage volume it enters the ordinary translational machinery; the excess is therefore encoded into polypeptide sequences without further geometric instruction. This establishes the claim. □

Remark 1. *The identical step-defect that the patent maps into nucleobase pairing therefore also, through the* C12*-tether geometry, supplies the* L*-amino-acid preference.*

3.4 D-Fructose and Downstream Sugar Stereochemistry via Scission-Generated Void

Definition 2 (Scission-Generated Void)**.** *A controlled bay scission (for example at the* C12a–C1 *bond) produces a non-planar five-membered heterocyclic protrusion that extends into the synthesis volume. This protrusion functions as a rigid master mould. A nascent chain forced to wrap about the mould retains, after sacrificial dissolution of the chrysene scaffold, a complementary cavity—a void (ghost pocket)—whose geometry and electrostatic profile are fixed by the original defect.*

Proposition 3 (D-Series Sugar Stereochemistry)**.** *The* D*-series sugar geometry is set by substituent-directed ring closure inside the constrained π-stacked lattice.*

1. *A substituent of the type* C3–O–C3α–C3β–OPO_3 *is present at the* C3 *position.*
2. *Linkage from* C1 *into* C3α *closes a five-membered ring, generating the fructose scaffold.*
3. *When this closure occurs within the steric and electronic confines of a π-stacked chrysene assembly, the chiral bay-region defect directs the facial approach of the ring-forming atoms and produces a void (Definition 2) complementary to the* D*-fructose (furanose) geometry.*
4. *The resulting void is stereochemically instructive: it preferentially stabilises the* D*-series configuration.*
5. *Because the enzyme that first acts on this sugar (phosphofructokinase) functions inside a metabolon, the stereochemistry fixed by the* D*-fructose void is retained in subsequent steps of the pathway, including the reverse direction toward gluconeogenesis. Consequently the same lattice-derived bias propagates to glucose and the other sugars of central metabolism.*

Proof of Proposition 3. Consider a π-stacked assembly in which a substituent of the form C3–O–C3α–C3β–OPO_3 is present and a controlled bay scission has generated the non-planar five-membered protrusion of Definition 2.
The scission protrusion occupies a definite volume inside the synthesis pore and presents a rigid, chiral surface. Ring closure by linkage of C1 to C3α must occur on the face of this surface that remains sterically accessible. The opposite face is occluded by the protrusion and by the neighbouring stacked chrysene units.
The accessible face corresponds to the facial approach that yields the D-fructose (furanose) absolute configuration. Consequently the newly formed ring is complementary, in both shape and electrostatic profile, to the void that remains after sacrificial removal of the chrysene scaffold.
Because the first enzyme that acts upon this sugar (phosphofructokinase) is embedded in a metabolon, every subsequent transformation—including the reverse direction that produces glucose—operates on a substrate whose stereochemistry has already been fixed by the void. The D-series configuration

is therefore transmitted through the entire central metabolic sequence.
This establishes the claim. □

Remark 2. *The chiral bay therefore does not merely select an already-formed sugar; it actively directs the positioning of the ring during formation and thereby sets the stereochemistry of the entire downstream sugar series.*

3.5 Unified Geometric Principle

Theorem 4 (Single-Defect Origin of the Three Biopolymer Biases)**.** *The chiral step-defect of Definition 1, acting together with the substitution and scission geometries of the tetrasubstituted chrysene lattice, constitutes a single geometric object that accounts for:*

1. *the mapping into paired nucleobases (Patent US 12,195,423);*
2. *the stereochemical packet of membrane lipids (hopanoids → sterols → cholesterol) (Proposition 1);*
3. *the statistical excess of* L*-amino acids (Proposition 2);*
4. *the preferential stabilisation of* D*-series sugars via scission-generated voids (Proposition 3).*

All four outcomes are images under Φ *of one and the same lattice defect.*

3.6 Simulation A – Parsimony of a Single Geometric Cause

To quantify the relative plausibility of a single chrysene step-defect versus a collection of independent abiotic processes, we compare the likelihood of observing the coordinated suite of five outcomes (nucleobase-pairing geometry, membrane-component incorporation, L-amino-acid excess, D-sugar void, and protein-encoded chirality) under two generative models.

Under the independent-causes model each outcome must arise separately with a modest success probability. Under the single-geometry model the step-defect, once present, generates the downstream outcomes with high conditional probability. Even when the independent model is given deliberately generous parameters, the posterior odds shift by many orders of magnitude in favour of the single-geometry explanation once all five features are required to co-occur.

```
# Simulation A - Single geometric cause vs independent processes

p_indep   = 0.02    # P(one correct outcome | independent process)
p_geom    = 0.85    # P(one correct outcome | step-defect present)
prior_odds = 1.0    # initial odds (geometry : independent)

for n in 1 to 5:    # n = number of coordinated features required
    lik_indep[n]  = p_indep ** n
    lik_geom[n]   = p_geom  ** n
    post_odds[n]  = prior_odds * (lik_geom[n] / lik_indep[n])

# Plot lik_indep vs n (log scale)
# Plot lik_geom  vs n (log scale)
# Plot post_odds vs n (log scale) and annotate final odds
```

Listing 1: Pseudocode for Simulation A

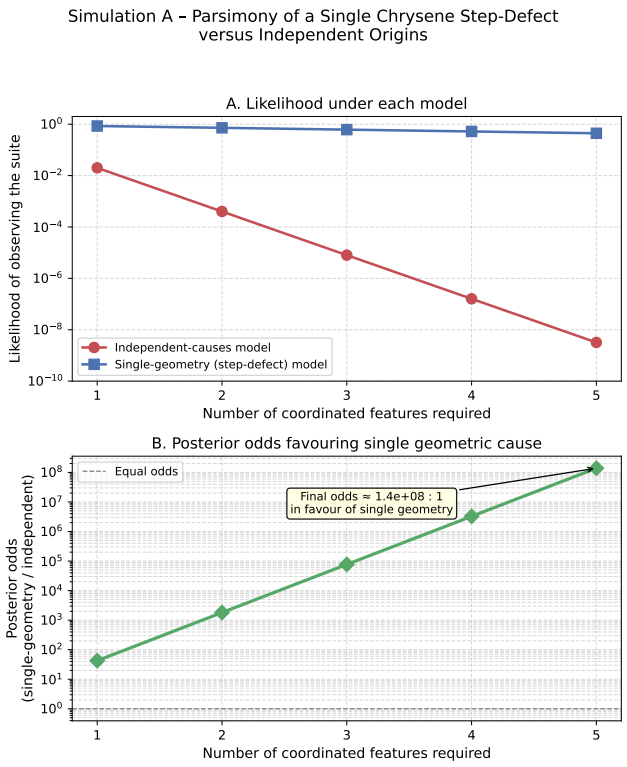

Figure 1: Simulation A – Parsimony comparison. Left: likelihood of observing an increasing number of coordinated features under an independent-causes model (red) versus under a single step-defect geometry (blue). Right: posterior odds favouring the single-geometry model. The numerical parameters used ($p_{\text{indep}} = 0.02$, $p_{\text{geom}} = 0.85$) are deliberately generous to the independent-causes model; the resulting odds therefore constitute a lower bound on the advantage of the single-geometry explanation.

4 Consistency with the Meteoritic and Biological Records

The geometric constructions of Section 2 are now confronted with the observational constraints fixed in Section 1. Each subsection records a distinct consistency; none is advanced as a uniqueness proof.

4.1 Sense of the Bias

Proposition 5 (Matching Handedness)**.** *Proposition 2 predicts a statistical excess of* L*-amino acids. Proposition 3 predicts preferential stabilisation of* D*-series sugars. Both predictions coincide in sense with:*

1. *the* L*-enantiomeric excesses of α-methyl amino acids and the* D*-enantiomeric excesses of aldonic acids recorded in carbonaceous chondrites;*
2. *the universal biological preference for* L*-amino acids and* D*-sugars.*

The geometric model therefore reproduces the observed handedness of both the pre-terrestrial and the terrestrial records.

4.2 Co-occurrence of Lattice and Excesses

Proposition 6 (Co-occurrence Consistency)**.** *Four-ring polycyclic aromatic hydrocarbons, including chrysene in multiple independent analyses, are indigenous constituents of the same carbonaceous chondrites that preserve the enantiomeric excesses of Section 1. Related PAHs are present in the interstellar medium and in returned asteroidal samples. The geometric object invoked by the model (the tetrasubstituted chrysene lattice and its step-defect) therefore belongs to a molecular family that already coexists, in the extraterrestrial organic inventory, with the only known pre-terrestrial chiral excesses of matching biological sense.*

Remark 3. *The model does not assert that dual-chrysene cages operated inside meteorite parent bodies. It asserts only that the same geometric principle is sufficient to generate a bias of the observed sense and that the requisite molecular skeleton is already present in the inventory that carries those excesses.*

4.3 Membrane Continuity

Proposition 7 (Membrane-Thread Consistency)**.** *Proposition 1 establishes that the step-defect is transmitted from the catalyst chrysene of the dual-cage volume into hopanoids and sterols, and persists into membrane-bound cholesterol. This continuous geometric thread is consistent with:*

1. *the characteristic absolute configurations of biological hopanoids and sterols;*
2. *the preservation of those configurations in the geological hopane and sterane records;*
3. *the presence of the identical sterol scaffold in contemporary eukaryotic membranes.*

The stereochemical packet of the membrane lineage is therefore the unbroken expression of the same lattice defect that the patent maps into the informational product.

4.4 Informational Continuity

Proposition 8 (Informational Consistency)**.** *Patent US 12,195,423 already maps the chiral step-defect into the geometry of paired nucleobases. Theorem 4 therefore closes the third biopolymer class by citation: the identical geometric object that accounts for membrane-lipid stereochemistry,* L*-amino-acid excess and* D*-sugar preference is the object that the patent maps into nucleic-acid pairing.*

4.5 Sugar-Void Consistency

Proposition 9 (Glycolytic Stereochemical Retention)**.** *The scission-generated void of Definition 2 and Proposition 3 produces a cavity complementary to* D*-fructose. Because phosphofructokinase operates inside a metabolon, the stereochemistry fixed at the fructose stage is retained in subsequent transformations, including the reverse direction toward gluconeogenesis. The lattice-derived* D*-bias is thereby consistent with the central position of* D*-fructose and* D*-glucose in terrestrial energy metabolism and with the* D*-excesses of related sugar acids in the meteoritic record.*

Remark 4 (Collective Consistency)**.** *Propositions 5–9 together establish that the principal empirical regularities—matching handedness of meteoritic and biological excesses, co-occurrence of the chrysene skeleton with those excesses, continuous membrane stereochemistry, patent-level informational mapping, and glycolytic retention of* D*-sugar geometry—lie inside the geometric envelopes fixed by the single step-defect of the tetrasubstituted chrysene lattice.*

Finer atomistic energy differences and quantitative amplification factors remain open experimental targets.

5 Testable Predictions and Open Questions

The geometric model of Section 2 generates a finite set of empirical consequences that can be confronted with existing or near-term data. Each prediction is stated as a formal claim; the corresponding open problems are recorded immediately thereafter.

5.1 Pocket Geometry and Enantiomeric Preference

Prediction 1 (Amino-Acid Pocket Selectivity)**.** *The* C12*-tether geometry of Proposition 2, bounded by the chiral step-defect and neighbouring π-stacked units, defines a local environment whose steric and electrostatic profile preferentially stabilises* L*-amino-acid geometries. Any synthetic or computational reconstruction of this constrained volume that fails to produce a statistical* L*-excess would falsify the geometric claim.*

Prediction 2 (Sugar-Void Selectivity)**.** *The scission-generated void of Definition 2 and Proposition 3 is complementary to the* D*-fructose furanose ring. Reconstructions of the bay-scission geometry that do not preferentially accommodate the* D*-series configuration, or that fail to retain that configuration through a metabolon-like sequence of transformations, would falsify the sugar-stereochemistry claim.*

5.2 Amplification under Aqueous Alteration

Prediction 3 (Parent-Body Amplification)**.** *If lattice-derived chiral environments of the kind formalised herein contributed to the enantiomeric excesses preserved in carbonaceous chondrites, then the magnitude of the excess should correlate with the extent of aqueous alteration in the manner already observed for isovaline and related α-methyl amino acids. The geometric model supplies a structured surface capable of participating in such amplification; it does not require that the lattice itself be the sole or primary agent.*

5.3 Residual Signatures

Prediction 4 (Residual Lattice Traces)**.** *Modern metabolites or kerogen-bound aromatic fractions may retain stereochemical or spatial signatures that still reflect the original step-defect bias—for example, non-random facial preferences in sugar-binding pockets or residual bay-region motifs in insoluble organic matter. Detection of any such residual correlation would constitute positive evidence; its absence would not constitute falsification, given the expected overprinting by subsequent evolution.*

5.4 Open Problems

The following questions lie beyond the present geometric resolution and define the frontier for subsequent work:

1. quantitative energy differences between L- and D-recognising configurations inside the amino-acid pocket and the sugar void;
2. the precise contribution of lattice-derived chiral environments relative to circularly-polarised-light and other abiotic mechanisms (the two classes of explanation are regarded as complementary rather than exclusive);
3. whether the same step-defect geometry can bias glycerol head-group stereochemistry (explicitly deferred);
4. the full stereochemical implications of the abiotic-loom architecture for α-helices, β-sheets and metabolon organisation (reserved for later work).
5. The lattice-derived chiral bias and circularly-polarised-light (or related photonic) mechanisms are regarded as complementary rather than exclusive: an external photonic process may supply a weak initial imbalance, while the persistent step-defect geometry supplies a structured local environment capable of reading and reinforcing that imbalance in the sense observed in both the meteoritic record and contemporary biology.

These open problems do not weaken the consistencies already established; they delimit the next empirical and computational targets required to move from geometric compatibility to quantitative verification.

6 Conclusion

The chiral step-defect of the tetrasubstituted chrysene lattice is a single geometric object.

Patent US 12,195,423 already maps it into paired nucleobases and, via the catalyst chrysene, into the membrane component. The same defect, constrained by the C12-tether geometry of the

dual-cage synthesis, produces a statistical excess of L-amino acids that is encoded into protein. Controlled bay scission generates a void complementary to D-fructose; because the first enzyme that acts on this sugar operates inside a metabolon, the stereochemistry fixed at the fructose stage propagates to glucose and the downstream sugars of central metabolism. The identical stereochemical packet persists from the dual-chrysene catalyst through hopanoids and sterols into membrane-bound cholesterol.

Theorem 4 therefore asserts that one lattice defect accounts for the handedness of the three major biopolymer classes. The same molecular family is present in carbonaceous chondrites that also carry the only known pre-terrestrial enantiomeric excesses of matching biological sense.

Homochirality is thereby framed as the biological amplification of a persistent geometric bias that was already available in the prebiotic and extraterrestrial organic inventory and that continues to operate, in attenuated form, inside contemporary metabolism. While atomistic energy differences and quantitative amplification factors remain open, the principal empirical regularities of the meteoritic, lipid and biological records already lie inside the geometric envelopes fixed by the chiral step-defect of the chrysene lattice.

A Literature Review: Homochirality, Meteoritic Excesses, and the Chrysene Skeleton

The empirical foundation of the present work rests on four interlocking observational domains: the pre-terrestrial enantiomeric excesses preserved in carbonaceous chondrites, the occurrence of chrysene-family polycyclic aromatic hydrocarbons in the same extraterrestrial inventory, the stereochemistry of biological and geological membrane lipids, and the principal abiotic mechanisms that have been proposed to generate chiral bias. The following summary records the principal constraints that any geometric model of homochirality must respect.

Meteoritic Amino-Acid Enantiomeric Excesses

Non-protein α-methyl amino acids, most notably isovaline, exhibit L-enantiomeric excesses in a range of carbonaceous chondrites. Typical values lie between 2 % and 18 %, with the higher figures reported for the more aqueously altered CM and CI lithologies (Murchison, Orgueil) [CP97, PC00, GD09]. Isotopic compositions of the individual enantiomers support an extraterrestrial origin for a substantial fraction of the measured excess [EM97, GD09]. Many of the most pristine meteorites, and the returned samples from Ryugu and Bennu, are racemic or nearly so, indicating that any initial bias is not universal and may be amplified under parent-body aqueous alteration [G$^+$20].

Meteoritic Sugar-Acid Enantiomeric Excesses

Several aldonic acids (threonic, erythronic and higher homologues) display D-enantiomeric excesses, frequently in the range 30–55 % [CR16, C$^+$18]. Glyceric acid, the smallest member, is generally racemic; the magnitude of the D-excess tends to increase with carbon number. Distributional and isotopic arguments again favour an indigenous source. The opposite sense of the amino-acid and sugar-acid excesses—L for amino acids, D for sugars—matches the handedness later adopted by terrestrial biology.

Chrysene and Polycyclic Aromatic Hydrocarbons in Meteoritic and Interstellar Material

Polycyclic aromatic hydrocarbons are indigenous constituents of carbonaceous chondrites. Four-ring species, including chrysene in multiple independent analyses, have been identified in Murchison, Murray, Orgueil and related meteorites [BMO84, Sep04, L$^+$22]. Related PAHs are widespread in the interstellar medium and have been detected in returned samples from the asteroids Ryugu and Bennu [S$^+$24]. The co-occurrence of the chrysene-family skeleton with the enantiomeric excesses recorded above constitutes a boundary condition of particular relevance to any model that invokes a chrysene-derived geometric bias.

Biological and Geological Lipid Stereochemistry

Biological hopanoids and sterols exhibit characteristic absolute configurations at defined ring junctions and side-chain centres. These configurations survive diagenesis and appear in the hopane and sterane biomarkers of the sedimentary record [ORP87, S$^+$88]. The sterol scaffold continues into contemporary eukaryotic membranes as cholesterol and related sterols, providing a continuous stereochemical thread from the geological record into modern biology [Blo83, Vol05].

Circularly Polarised Light and Other Abiotic Mechanisms

Ultraviolet circularly polarised light (CPL) can induce small enantiomeric excesses by asymmetric photolysis or asymmetric synthesis [B$^+$98, M$^+$14b, M$^+$14a]. Laboratory experiments typically produce excesses of a few percent. Infrared circular polarisation has been observed in star-forming regions, although the ultraviolet CPL most relevant to amino-acid photochemistry remains indirectly constrained [B$^+$98, K$^+$16]. CPL is regarded here as a complementary external agent capable of supplying a weak initial imbalance; it does not by itself explain the opposite handedness of amino-acid and sugar excesses, nor the structural continuity of membrane-lipid stereochemistry.

Summary of Empirical Boundary Conditions

Collectively the literature establishes that:

1. carbonaceous chondrites preserve L-amino-acid and D-sugar-acid excesses of extraterrestrial origin;
2. the same meteoritic inventory contains indigenous chrysene-family PAHs;
3. biological and geological membrane lipids carry a continuous stereochemical packet;
4. CPL and related photonic mechanisms can generate small initial excesses but leave the coordinated structural biases across biopolymer classes unexplained.

These observables constitute the experimental boundary conditions against which the geometric predictions of the chrysene step-defect are tested in the main text.

B Relation to the Chrysene Formalism Corpus

The present work forms part of a continuing program whose experimental starting point, pure-mathematical foundations and successive biological applications have been set out in earlier publications. We record here the precise dependence of the chiral step-defect analysis on that corpus.

Empirical Origin

The concrete molecular geometry from which the entire Formalism is abstracted is the demonstration that nucleic-acid sequences integrated within a phospholipid enclosure can be generated directly from a substituted chrysene precursor [Sch25]. That composition-of-matter result already maps the chiral step-defect of the tetrasubstituted lattice into the geometry of paired nucleobases and, via the catalyst chrysene of the dual-cage volume, into the membrane component. The present paper extends the same defect into the stereochemistry of amino acids and sugars, thereby closing the three major biopolymer classes under one geometric object.

Pure-Mathematical Framework

Two complementary volumes develop the underlying mathematics. The first constructs the discrete non-commutative state space, its cohomological invariants and the associated operator algebras [Sch26b]. The second supplies the tensorial and algebraic-geometric structure that governs maximal-entropy survival under topological strain [Sch26f]. A further volume situates the same geometry within a broader algebraic account of the continuity of life [Sch26g]. The lattice-preserving character of the step-defect and the scission-generated voids employed herein are instances of the general class of structure-preserving maps defined in those works.

Metamaterial and Biological Realisations

Subsequent articles in the *Annals* apply the Formalism to successive layers of organisation. One examines the tetrasubstituted chrysene lattice as a programmable topological metamaterial capable of self-assembly and quantum-information encoding [Sch26e]. Another treats the dual-chrysene reactive volume as the source of the observed hopanoid–sterane asymmetry and of the transition from environmental to endogenous membrane scaffolds [Sch26a]. A third presents the claim that a single encodable topological metamaterial accounts for the origin, the intelligence architecture and the evolutionary trajectory of life [Sch26h].

The macromolecular aromatic networks of pre-Cambrian kerogen have been interpreted as a geometric archive of the same lattice, preserving characteristic length scales, bridge chemistry and metal-integration motifs [Sch26d]. Most recently, the dual-chrysene metal cage has been shown to rearrange into an $18\,\pi$-electron, metal-coordinated macrocycle whose carbon numbers fall inside the observed window of the 1.1 Ga geoporphyrin record [Sch26c].

Position of the Present Work

Collectively these works establish a single geometric object—the tetrasubstituted chrysene lattice and its chiral step-defect—whose successive images under the realisation map Φ account for:

1. the integrated synthesis of nucleic acid and phospholipid (the patent);
2. the hopane/sterane temporal asymmetry and membrane-lipid stereochemistry;
3. the macromolecular architecture of pre-Cambrian kerogen;
4. the 1.1 Ga geoporphyrin record;
5. the present-day biological biases toward L-amino acids and D-sugars, together with the continuous stereochemical packet of membrane lipids (the present paper).

The chiral step-defect analysed here is therefore not an isolated hypothesis; it is the stereochemical instance of a uniform geometric principle already shown to organise informational, membrane, residual-organic and metal-macrocycle archives across the pre-Cambrian and into contemporary biology.

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