All Facts and Theories of Physics and Chemistry Derived from the Vacuum.Net Theory

A reference work from the first distinction to the climate and climate change. Third edition, judged under the Respondent–Judge protocol

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Base text: *The Vacuum.Net Theory*, Ninth Edition (Foundations 9.2 and Physics 9.0), Leiden, 27 October 2026. Theorems from that text are cited as Foundations Tn and Physics Tn. Theorems new in this book are numbered B1, B2, and so on.

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Part 0 — The Short Book

This part tells the theory in plain steps. Each chapter shows how standard physics or chemistry handles a subject, how the net handles it, and one example you can check with a pocket calculator. After this part the book continues with the full version: proofs, sources and the status of every claim.

S1. One Strand

The standard view. The world has space, time, fields and particles. Each needs its own laws and its own constants.

The net. There is one strand. Nothing else exists. The strand runs and crosses itself. Light is one place on the strand that moves one step per tick. Length and time are counts of steps and ticks. Every measured quantity is a ratio of two counts.

What becomes simpler. The speed of light is one step per tick. Planck's constant and the gravitational constant are conversions between human units. They are not separate laws. Only pure numbers without a unit remain to be explained, such as the fine-structure constant 1/137.036.

Check it yourself. The second was 1/86,400 of the mean solar day until 1960. Since 1967 it is 9,192,631,770 periods of the radiation of a hyperfine transition of caesium-133. Since 1983 the metre follows from a fixed speed of light. The reference moved from the turning Earth to an atomic cycle; by N7 every unit is read as a count of one cycle against another.

Basis. Assumed: axioms N1, N6 and N7 (Chapter 1). The statements of S1 follow from the axioms; they are not proven.

S2. Closure of Three

The rule. Read the strand in values $-1, 0, +1$. Take three values in a row: a window. The window closes when the sum is a multiple of three. What closes persists. What does not close passes on as tension.

Three ways to close.

Closure	Example	Sum
Standing	0	0
Meeting	$+1, -1$	0
Ring	$+1, +1, +1$	3

Check it yourself. There are $3^3 = 27$ windows. Exactly 9 close: the three where all values are equal, and the six where all values differ. That is one in three.

A first consequence. Doubling (meetings) and tripling (rings) never meet: 2^n is never 3^k. At twelve steps they come closer than at any smaller depth (closer misses follow at 41 and 53). The miss is $3^{12}/2^{19} = 1.01364$, the Pythagorean comma of 23.46 cents that every piano tuner knows.

Basis. Count of windows and comma: proven (Chapters 3, 6). “What closes persists”: axiom N2. Doubling and tripling as meetings and rings: proven under hypothesis (equal blocks, T15).

S3. Matter

The standard view. There are many particles, each with its own mass, charge and spin, sorted into the Standard Model.

The net. The net reads a stable particle as a closed loop of the strand. The net identifies the electron with light closed on itself in a double loop. Spin ½ is read as the return of the loop after two full turns. Charge is read as a winding number, which cannot change without cutting the strand. The proton is read as a closure of three windings with charges $+2/3$, $+2/3$, $-1/3$.

Check it yourself: which combinations exist? Count each part as $+1$ and each anti-part as -1. A combination can exist alone only if the total is a multiple of three.

Combination	Total	Seen alone?
three parts (proton, neutron)	3	yes
part and anti-part (pion)	0	yes
two parts	2	no
two parts and two anti-parts (tetraquark)	0	yes
four parts and one anti-part (pentaquark)	3	yes
one part (free quark)	1	no

For up to three parts the closure rule of S2 is exactly the zero-triality rule of particle physics; for four and five parts the rule is applied to a longer word.

Mass. In a loop the light location turns back. The more turns per step, the lower the speed of the loop as a whole, and the heavier it is. Inertia is how often light turns back in a loop; weight is the shift of the passage density around the loop (15.6). That the two are equal is not derived.

Basis. Spin and charge: proven under named assumptions (Chapter 7); their identification with electron spin and electric charge: read (C2, 14.3). Electron as a loop: identification (15.1).

Proton: read; particle rule: translated, exact for up to three parts (15.5). Mass as turning: proven in one space dimension under H-D1 (25.2); weight equal to inertia: open (15.6).

S4. Light and Gravity

The standard view. Gravity is the curvature of space-time (Einstein). Maxwell tried in 1864 to describe it as a state of a medium and stopped: the medium would need "an enormous intrinsic energy".

The net. Around every loop the passage density of the strand differs from its reference value (H-G1; one sign for all loops is not derived). Two loops that change it in the same way attract each other. All field energy stays positive; Maxwell's difficulty does not arise. Newton's $1/r$ is not yet derived: the range is finite (25.6, 25.7).

Light near the Sun. Assume that near a mass one step is shorter and one tick longer by the same fraction (H-S, fixed by measurement). Seen from far away, light then moves slower, as in glass. It bends by refraction, as Snellius described around 1621.

Check it yourself. The bending of a ray that grazes the Sun is $4GM/\left(c^2R\right)$. With $GM = 1.327 \times 10^{20}$ m³ s⁻², $c = 2.998 \times 10^{8}$ m s⁻¹ and $R = 6.957 \times 10^{8}$ m this is 8.49×10^{-6} radian, or 1.75 arc seconds. This agrees with measurement (Cassini: $\gamma_{\mathrm{PPN}} = 1$ to 2×10^{-5}).

Gravity and electricity. The net reads electricity as the vector part of the strand's field and the static part of gravity as its scalar part. Between two protons gravity is weaker by a factor of about 10^{36}: the ratio is 8.1×10^{-37}. It equals $\left(m_p/m_{\mathrm{Planck}}\right)^2/\alpha$: if one step is the Planck length (an identification, not derived), gravity is weak because the loops are long compared with one step.

Basis. Attraction: proven under one named assumption (25.6). Step and tick shifting together: an assumption fixed by measurement (25.8). Gravity as the scalar part: a reading of its static part; its moving part is open (25.9). The ratio 8.1×10^{-37}: an exact identity; "loops are long": an identification (25.9). Deflection also uses the Newtonian potential as input (B16).

S5. Atoms

The standard view. Electrons fill shells according to the Schrödinger equation and the Pauli principle.

The net. A shell is a set of closed states. Two electrons with opposite spin form a meeting $(+1, -1)$: one closure.

Check it yourself. Shell n holds $2n^2$ states: 2, 8, 18, 32. In the order in which the shells fill, the rows of the periodic table have lengths 2, 8, 8, 18, 18, 32, 32. Each is twice a square. In the net reading, closed outer s and p subshells leave no open window; helium, neon and argon hardly react (17.4).

Basis. Proven, with the filling order as input (Chapters 16, 17).

S6. Molecules

The standard view. Bonds follow from quantum chemistry: orbitals, overlap, energy minimisation.

The net. The net reads a bond as a meeting between two atoms. Four short rules hold, each checkable by counting; the ring rule needs the tight-binding input.

Rule	Check	Example
The sum of the valences is even	Every bond has two ends	CH_4: 4 + 1+1+1+1 = 8, four bonds
An odd number of electrons leaves one open	Add the atomic numbers	NO: 7 + 8 = 15, odd: NO is a radical
Charges must close	Find oxidation states that add up to the charge	$FeCl_3$: +3 − 3 = 0, passes (and exists); $NaCl_2$: +1 − 2 = −1, fails (not a known compound)
A ring with $4n + 2$ shared electrons closes	Count the ring electrons	Benzene: 6 = 4·1 + 2, stable; cyclobutadiene: 4, unstable

A fifth rule counts rings. Rings plus extra bond orders equal bonds minus atoms plus one. Benzene, C_6H_6: 15 bonds counted with order, 12 atoms, $15 - 12 + 1 = 4$: one ring and three double bonds.

A limit. Oxygen, O_2, has an even count (16) and still has two unpaired electrons. The rules are necessary, not sufficient.

Basis. Proven (Chapters 18, 19; bond as meeting: read; fifth rule in formula form under the valence hypothesis, B4; charge rule under the table of oxidation states; ring rule under input, 25.3).

S7. The Climate

The standard view. Radiation balance, greenhouse gases, feedbacks, climate models.

The net. A steady planet returns to space what it receives; the net reads this as a closure, and the difference as tension that passes on as warming.

Check it yourself.

- Without an atmosphere: $T = \left[S(1-A)/4\sigma\right]^{1/4}$ with $S = 1361$ W m^{-2}, $A = 0.30$, $\sigma = 5.67 \times 10^{-8}$. This gives 255 K. The surface is at about 288 K. The difference of 33 K is the atmosphere.
- Each doubling of CO_2 adds the same forcing, 3.93 W m^{-2}. The net reads a doubling as one step on the ladder of meetings.
- Without feedbacks, for a uniform black body at 255 K, one doubling warms by $3.93/3.74 = 1.05$ K; the IPCC Planck response (3.22) gives 1.22 K.
- How strongly the climate responds is not a constant; it depends on the state of the planet.
- Up to 2100 the Sun, the Earth's orbit and the planets change the forcing by about a tenth or less of the CO_2 forcing; a planetary influence through the Sun is not established (23.8).

Basis. Computed from measured inputs; the logarithm proven under stated idealisations; closure, the doubling as a step and sensitivity as a state function: read (Chapters 22, 23, 25.4).

S8. Side by Side

Subject	Standard physics and chemistry	The net
What exists	Space, time, fields, particles	One strand
Constants	c, h, G and about 25 numbers	Ratios of counts; c, h, G are conversions
Which particles exist	Colour rule of SU(3)	Closure of three
Spin ½	Property of the wave function	Return after two turns
Charge conservation	Symmetry (Noether)	Topology of the strand (under named hypotheses)
Gravity	Curved space-time	Static part: passage density (read); light refracts (under H-S); moving part open
Shells and periods	Schrödinger + Pauli	Count of closed states
Bonds	Orbitals	Meetings; four counting rules
Climate sensitivity	A number to be measured; state dependence known (pattern effect)	A function of the state of the planet (read)

What the net still has to deliver. Among other open links (Chapter 26: Newton's $1/r$, the moving part of gravity, κ), the pure numbers: the fine-structure constant 1/137.036 and the proton–electron mass ratio 1836.15. Chapter 28 states, for each of them, the test a derivation must pass.

From here on. The rest of the book gives the full version. Every statement of this part is given a status there (proven, input, read, identified or open), with sources and calculations. The next pages summarise the claims with their basis.

What Is Different: the Claims and Their Basis

This is a different physics. It starts from one strand and nothing else. The short book above told it in steps; this list gives each claim with its basis. Each statement below is short. The right column gives its basis: axiom, theorem, or reading. The chapters give the proofs.

The ground

Statement	Basis
There is one strand and nothing besides it. Where older texts say “medium”, this book means the strand as a whole of windings: the net.	Axiom N1 (1.3)
What closes persists. What does not close passes on as tension.	Axiom N2
A window of three trits closes when its sum is 0 mod 3. Exactly 9 of the 27 windows close.	Proven (Foundations T3, T4)
Every closed word reduces to nothing by standing, meeting and ring.	Proven (Foundations T7)
Two ladders, of meetings and of rings, never meet. At depth 12 they miss by the Pythagorean comma, 23.46 cents.	Proven (Foundations T16–T18)
The first knot that cannot be undone has three crossings and a mirror twin.	Proven under named hypotheses (Foundations T19, T20)

Light and measure

Statement	Basis
Light is a place on the strand. It moves one step per tick.	Axiom N6
Length and time are counts. Every measured quantity is a ratio.	Axiom N7
The speed of light, Planck's constant and the gravitational constant are conversion factors between human references. They are not laws of nature.	Axiom N7
Only dimensionless numbers are targets: α, m_p/m_e and a short list more.	Axiom N7; listed in 25.9

Matter

Statement	Basis
A stable particle is a closed winding.	Read (C4)
The electron is light closed on itself in a double loop.	Identified (I1)
Spin ½ is the return after a turn of 4π.	Proven under the quaternion hypothesis (T21); identification with spin read (C2)
Charge is read as a winding number, the Hopf charge. That number is conserved by topology alone.	Read; conservation proven under named hypotheses (T22)
In 1+1 dimensions the reversal amplitude enters exactly as mass: $E^2 = p^2 + m^2$. Mass is how often light turns back in a loop.	Proven in 1+1 dimensions under H-D1 (B10); the reading is read (25.2)
A shorter loop is heavier.	Read (15.6); the reversal per loop length is open
The proton is a closure of three windings with charges in thirds.	Read (15.5)
Only states whose parts minus anti-parts are divisible by three are observed. For up to three constituents this is exactly the closure rule $x + y + z \equiv 0 \pmod 3$.	Translated (15.5)
Binding energy is tension released at a closure.	Read (15.7)

Field and gravity

Statement	Basis
The structure of Maxwell's quaternion equations follows from the step differences of a flat net: no free magnetic source, closed total current, Faraday's law. The gauge sits in the scalar register. K, C, μ and the force law are input.	Proven under H-Q1, H-Q2 (B9)
In a net with positive field energy and sources coupled linearly, like sources attract. Maxwell's "enormous intrinsic energy" is not needed.	Proven under H-G1 and $\bar{g} > 0$ (B14, points 1–4); one sign of mass and Newton's $1/r$ open (R16, R17)
The lever of a free path and the coupling of the net are one number: $\gamma = -3.94$.	Proven under H-R and T24 (B15); H-R read (R8)
Light passing the Sun is refracted by a graded index. Snell's law (Snellius, Leiden, about 1621) then gives 1.75″ at the limb.	Proven under N6, H-S (input, equivalent to $\gamma_{\mathrm{PPN}} = 1$) and the Newtonian potential (input) (B16)
The ratio 10^{-37} of gravity to electric force is α and one length ratio, not a separate number.	Proven (identity, 25.9)
Inertia and weight are two counts of one loop.	Read; their equality open (R17)

Chemistry and the planet

Statement	Basis
Shell n holds $2n^2$ states. The periods have lengths 2, 8, 8, 18, 18, 32, 32.	Proven under input (B1, B2)
In every molecule with an integer bond graph the valence sum is even. An odd electron count leaves at least one electron unpaired: one window open.	Proven (B3, B7); "window open" read
Every bond beyond a spanning tree closes one cycle: rings plus extra bond orders equal $B - N + 1$ (bonds counted with order).	Proven under the valence hypothesis (B4)
A ring with $4n + 2$ shared electrons closes: the rule of aromaticity.	Proven under input (B11)
Reaction heat does not depend on the path.	Proven under input (B6)
1,183 compounds were checked against the closure rules.	Computed (Ch. 19, App. C)
Each doubling of CO_2 adds the same forcing. The logarithm is a count of doublings.	Proven under H1–H4 (B12); the count of doublings is read
Climate sensitivity is a state function, not a constant.	Read (N4)
To 2100 the Sun, the orbit and the planets are an order of magnitude below the CO_2 forcing.	Computed; known (23.8); a planetary influence via the Sun is open

What comes next

Twenty-nine questions remain. Each has its test fixed in advance (Chapter 28). The largest are α and the ratio 1836.

How to Read This Book

The aim

This book starts from one act: a distinction. It then follows one chain. The chain runs through number, knot, motion, field, matter, the atom, the molecule, the planet and the climate.

The title states the aim. The text states, at every step, how far the aim is reached.

Eight status words

Every statement in this book carries a status. The status words are those of the Respondent–Judge protocol (Chapter 27); its word “corresponded” is split here into “translated” and “read”.

Status	Meaning
proven	Follows by proof. Where hypotheses or external inputs are used, they are named (“proven under …”).
computed	Checked by exact computation over a stated finite range, not proven in general.
input	Taken from outside the theory and named as such.
translated	An exact one-to-one map between an object of the net and a known result: the same mathematics in two languages.
read	A declared reading of a known result in the language of the net. It can fail.
open	No chain yet connects the axioms to the result.

Status	Meaning
known	Already in the literature; the source is given. “New” is a note, not a status.
refuted	Contradicted by an independently re-checked counterexample.

A numerical outcome the theory commits to in advance is marked “registered prediction” as a note. A missing step found by a judge is marked GAP.

A known result that is only read is not called derived. A result that is open is called open. This keeps the book usable as a reference: a reader can see at once which links hold by proof, which links are readings, and what each judge found.

How to use this book as a reference

- Appendix G lists every theorem with its status and the judge’s verdict.
- Appendix D lists the verdicts of the four judges per family of claims.
- Appendix E gives the terms of the net; Appendix F the constants and inputs.
- Appendix H translates the terms of physics and chemistry into the terms of the net, with status.
- Appendix I lists the standard objections and where the book answers them.
- Chapter 28 defines what remains to be found, with a solution criterion fixed in advance.
- Appendix C gives the closure check of 1,183 compounds.

Rules of the text

- Sentences are short. The tone is factual.
- Exact calculations are in Appendix A. The record of the checks is in Appendix B.
- References are in footnotes.
- Every number in this book was recomputed for this edition. Every qualitative claim about the present state of science was checked against a second source.

Language

The book uses the words of the net: strand, loop, window, closure, tension, carry, ladder, knot, state function. Where the literature uses words with an actor (“a gas traps heat”, “a catalyst drives a reaction”), the book rewrites the statement as a relation: what closes, what stays open, what passes on.

The chain in one view

Step	Content	Chapter	Status
1	The first distinction; seven axioms	1	input (ground, N1–N7); readings: read
2	The trinity and its arithmetic	2	proven; trit rule GAP at ends
3	The window of three; closure	3	proven
4	Three elementary closures	4	proven
5	Addresses and counts	5	proven; shares computed
6	Two ladders and the comma	6	proven
7	The first knot, rotation, charge	7	proven under named hypotheses
8	Coupling of the net	8, 25.7	proven under named hypotheses; lever = coupling under H-R
9	Motion: Dirac and nilpotence	9, 25.2	proven (identity); proven in 1+1 dimensions under H-D1
10	Field: Maxwell's two registers	10, 25.1	read; structure proven under H-Q1, H-Q2

Step	Content	Chapter	Status
11	Measure: units from hydrogen	11	proven (map); input (reading, constants)
12	Loss and the second law	12	known (de Groot–Mazur)
13	Mechanics and gravitation	13, 25.6	read; known; sign of static coupling proven under H-G1
14	Light, relativity, quantum	14, 25.8	read; light deflection proven under H-S; open
15	Particles and nuclei	15	read (three windings, triality, released tension); open (O3, O7)
16	The atom	16	proven under input (atomic spectrum)
17	The periodic table	17	proven under input (Madelung order)
18	The chemical bond	18	proven (graph part); read

Step	Content	Chapter	Status
19	All compounds	19	proven (counting rules); computed (1,183 entries); open (single compounds)
20	Reactions and energy	20	proven under input; read
21	Matter in bulk	21	read
22	The climate	22	proven under input; read
23	Climate change; external influences (Sun, orbit, planets)	23	input; proven under hypothesis; computed; known; open
24	The ledger	24	summary
25	Links reduced	25	proven under named hypotheses; known
26	Links that stay open	26	open
27	Method	27	—
28	Research agenda	28	open (criteria fixed)

Part I — The Ground

1. The First Distinction

In short.

- One act starts everything: a distinction (ground).
- There is one strand; what closes persists; order is kept; response depends on state; scale repeats; light moves one step per tick; all measure is ratio (N1–N7).
- There is no medium beside the strand.

1.1 The act

Draw a distinction. A mark splits a space into an inside and an outside. This is the first act of Spencer-Brown's *Laws of Form*.[1] Two laws govern marks. Calling twice is calling once. Crossing twice is not crossing.

1.2 Re-entry

A mark that contains itself cannot settle. It alternates: marked, unmarked, marked. Kauffman reads this alternation as an iterant $\left[+1, -1\right]$ together with a time shift η, with $\eta^2 = 1$ and the swap rule $\eta\left[a, b\right] = \left[b, a\right]\eta$. Iterants multiply place by place. The product $i = \left[+1, -1\right]\eta$ then satisfies

$$i^2 = -1 .$$

Check. $i^2 = \left[1, -1\right]\eta\left[1, -1\right]\eta = \left[1, -1\right]\left[-1, 1\right]\eta^2 = \left[-1, -1\right] = -1$. Without the swap rule the product would be $+1$.

The imaginary unit is read as the oscillation of a self-referring distinction.[2] A familiar mathematical object is read off here; the shift η and its swap rule are put in by hand. Status: read (Foundations II.3).

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[1] G. Spencer-Brown, *Laws of Form*, Allen & Unwin, London, 1969.

[2] L.H. Kauffman, "Imaginary values in mathematical logic", *Proceedings of the Seventeenth International Symposium on Multiple-Valued Logic*, IEEE, 1987, 282–289; for the iterant notation see R. Ul Haq and L.H. Kauffman, "Iterants, idempotents and Clifford algebra in quantum theory", arXiv:1705.06600, 2017.

1.3 The strand

The Vacuum.Net states the same act in the language of a strand.

Definitions. An ordered index set I is the course of the strand. A set P holds the places. The strand is a map $\sigma : I \to P$. A loop is a pair $i < j$ with $\sigma(i) = \sigma\left(j\right)$: the strand returns to a place it has been. A node is a place visited at least twice.

Axioms. Seven axioms carry the theory. N1–N5 are those of the Ninth Edition. N6 and N7 were added by the author for this edition (6 November 2026).

	Axiom	Content
N1	Strand	There is exactly one strand. Every distinction is a loop.
N2	Closure	A loop persists if and only if it lies in a closed window. What does not close passes on as tension.
N3	Memory	At every node the passages are ordered. The first passage fixes the direction.
N4	Context	The response of the net is a state function, not a universal constant.
N5	Scale	Merged into blocks, the coarse strand obeys N1 to N4 again. What does not close at one scale is the material of the next.

	Axiom	Content
N6	Light	Light is a location on the strand. It moves one step per tick.
N7	Ratio	Length and time are not variables of the strand. They are references that observers take from a cycle, historically the day of sun and moon. Every measurable quantity is a ratio of counts.

No medium. By N1 there is nothing besides the strand. Where the Ninth Edition writes "medium" (N4, Foundations T23, IX.1), it means the strand seen as a whole of windings. This book writes "the net".

1.4 The eigenform

Kauffman calls a form that reproduces itself under an operation an eigenform: $O(A) = A$.[3] N2 says that only what closes persists. Chapter 4 shows that on the register the rings that close everywhere are exactly the fixed points of one rewrite. N2 thus has the form of the eigenform condition.

1.5 Light and measure

N6 makes motion primary. The light location never rests and never changes speed: one step per tick. Everything that moves slower than light is a loop in which the location turns back (Chapter 25.2).

N7 makes measure secondary. A unit is the number of times one winding fits in another. Human practice shows the sequence. Until 1960 the second was 1/86,400 of the mean solar day. From 1960 it was a fraction of the tropical year. Since 1967 it is 9,192,631,770 periods of a transition

[3] L.H. Kauffman, "EigenForm", *Kybernetes* 34(1/2), 2005, 129–150.

in caesium-133. Since 1983 the metre follows from a fixed value of the speed of light.[4] The reference moved from a large winding (the earth's turn and its orbit about the sun) to a small closed loop (the atom). Both are windings of the strand.

N7 follows Leibniz's relational position against Newton: space is "an order of coexistences, as time is an order of successions".[5] In the net the order of successions is N3.

Status of this chapter: assumed (the ground and N1–N7); 1.2 and 1.4 are readings (read).

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[4] BIPM, *The International System of Units (SI)*, 9th ed., 2019, and bipm.org, "SI base unit: second"; history of the definition in Innovation and Technology Commission Hong Kong, "Time (the second, s)".

[5] G.W. Leibniz, third paper to Clarke (1716), §4 in the Newton Project edition (Oxford); numbered §7 in the extract of the University of Cincinnati; see *The Leibniz–Clarke Correspondence*, ed. H.G. Alexander, Manchester University Press, 1956.

2. The Trinity

In short.

- Three values suffice: −1, 0, +1 (balanced ternary).
- Every integer has exactly one balanced residue mod 3 (proven).
- One mechanical rule gives a trit to every later passage through a node (definition; GAP at the ends and in one ambiguous case, 2.3).

2.1 Three values

Beneath the axioms lies one ground: three values $-1, 0, +1$ whose sum is zero. They are written T, 0, 1. They are the digits of balanced ternary.

Foundations T1 (The trinity as register). For a sum s of trits, the digit is the balanced residue $d \in \{-1, 0, +1\}$ with $d \equiv s \pmod 3$. The carry $(s - d)/3$ passes to the next position, one scale higher. Then:

1. A sum leaves no residue at its own scale if and only if $s \equiv 0 \pmod 3$.
2. What it does not keep passes on, whole, as carry.
3. The residues form $\mathbb{Z}_3$, the smallest cyclic group in which a value differs from its reverse.

Proof. The set $\{-1, 0, 1\}$ is a complete residue system modulo 3, so every integer has exactly one balanced residue. In $\mathbb{Z}_2$ we have $1 = -1$. In $\mathbb{Z}_3$ we have $-1 = 2 \neq 1$. ∎ Status: proven.

2.2 What this gives

The rule of N2 and N5 is now arithmetic. What closes at a scale leaves digit 0 there. What does not close is either kept as a nonzero digit (tension) or carried to the next scale.

2.3 The trit rule

A later passage through a node gets a trit by one mechanical rule. Let f be the first passage through that node.

- $t = +1$ if the passage leaves the node the way the first passage left it.
- $t = -1$ if it leaves the way the first passage came in.

- $t = 0$ otherwise.

The rule uses only σ.

Gap in the rule. The rule is not defined at the ends of the strand, where $i + 1$ or $f - 1$ does not exist. It is also ambiguous when the first passage leaves the way it came in ($\sigma(f + 1) = \sigma(f - 1)$): then $+1$ and -1 both apply. The Ninth Edition lists the physical reading of the rule as open (IX.5); these two cases belong to that open point. Status: GAP.

2.4 Why three

The cost of writing N in radix r grows as $r/\ln r$. The values are 2.885 for $r = 2$, 2.731 for $r = 3$ and 2.885 for $r = 4$. The continuous optimum is $r = e = 2.718$. Three is the integer radix closest to the optimum (Appendix A.1). This agrees with T1 but does not prove it. T1 rests on direction, not on cost.

2.5 The balanced notation

Balanced ternary needs no minus sign and no rounding rule.[6]

Property	Balanced ternary	Binary / decimal
Sign	Leading nonzero trit	Separate sign
Negation	Swap $1 \leftrightarrow \mathrm{T}$	Separate rule
Truncation	Equals rounding to nearest	Needs a rounding rule
Shift by one place	Multiply or divide by 3	Multiply or divide by the radix

Example: $8 = 10\mathrm{T}$ (that is $9 - 1$) and $-8 = \mathrm{T}01$.

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[6] D.E. Knuth, *The Art of Computer Programming*, Vol. 2, 3rd ed., Addison-Wesley, 1997, pp. 195–213.

3. The Window and Closure

In short.

- A window is three trits (proven, T2).
- Exactly 9 of 27 windows close: all equal or all different (proven, T3, T4).
- Under a uniform law one window in three closes (proven, T6).

3.1 The window of three

Foundations T2. A run of equal nonzero trits leaves no residue first at length three. A window is therefore three consecutive trits. It closes when

$$x + y + z \equiv 0 \pmod 3 .$$

Proof. A run of k equal trits has sum $k\,x$. Its residue is zero first at $k = 3$. ∎ Status: proven.

A closed run returns to its start. It is a loop one scale up. This is N5 at work.

3.2 Nine of twenty-seven

Foundations T3 and T4. Exactly 9 of the 27 windows close. A window closes if and only if its three trits are all equal or all different. There are 3 homogeneous and 6 heterogeneous closing windows. The 18 open windows all have exactly two equal trits.

Proof. The sum map $\mathbb{Z}_3^3 \to \mathbb{Z}_3$ is a surjective homomorphism. Its kernel has $27/3 = 9$ elements. All equal to a gives $3a \equiv 0$; all different gives $-1 + 0 + 1 = 0$: both close. Two equal trits a and one other b give $2a + b \equiv 0$, hence $b \equiv a$: a contradiction, so these do not close. ∎ Status: proven; recomputed by enumeration (Appendix A.2).

The rule “all equal or all different” is the rule of Fox three-colouring at a knot crossing.[7] The register and the first knot obey one rule.

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[7] R.H. Fox and R.H. Crowell, *Introduction to Knot Theory*, Ginn, 1963; Springer GTM 57, 1977.

3.3 Closure probability

Foundations T6. Let the trits be independent with law (p_0, p_1, p_T). With $\hat{p}(z) = p_0 + p_1 z + p_T z^2$ and $\omega = e^{2\pi i/3}$, a window closes with probability

$$\Pr(\text{close}) = 1/3\left[1 + \hat{p}(\omega)^3 + \hat{p}\left(\omega^2\right)^3\right].$$

The uniform law gives $1/3$. Status: proven under named hypotheses.

4. Three Elementary Closures

In short.

- Standing, meeting and ring remove every closed word (proven, T7).
- A word closes in every window only with period 3 (proven, T8).
- A ring closes at its own scale and becomes one passage of the next (proven).

4.1 Standing, meeting, ring

Foundations T7. Every closed trit word reduces to nothing by removing, one at a time,

- a **standing**: 0 (length 1),
- a **meeting**: $x, -x$ (length 2),
- a **ring**: x, x, x (length 3).

No open word reduces. The winding number of a word with nonzero steps is its integer sum divided by 3. Among closures with nonzero steps, the meeting is the shortest with winding number 0 and the ring the shortest with winding number ± 1.

Proof. Each removal takes away a piece with sum $\equiv 0 \pmod 3$, so it keeps the sum of the word modulo 3; an open word can therefore never reach the empty word. Conversely, let a word be closed. Remove every 0. Then cancel adjacent pairs $x, -x$ until none is left. Two different nonzero trits are opposite, so what remains has a single sign. Its sum is $L \cdot x \equiv 0$, so 3 divides its length L, and it splits into rings. ∎ Status: proven. Recomputed for all 9,841 closed words of length 1 to 9 (Appendix A.3); the independent judge checked every removal order up to length 10, all words of length 11 to 13, and 20,000 random words of length 14 to 40.

4.2 What a closure carries

Foundations T7.1. A standing and a meeting close with carry 0. A ring closes with carry ± 1:

$$1 + 1 + 1 = 10, \qquad \mathrm{T} + \mathrm{T} + \mathrm{T} = \mathrm{T}0\,.$$

A ring closes at its own scale and becomes one passage of the next. This is N5 as arithmetic. Status: proven.

This distinction returns in every later part of the book. A **meeting** closes without passing anything on. A **ring** closes and passes one unit to the next scale.

4.3 Words that close everywhere

Foundations T8. A word of length $n \geq 3$ closes in every window if and only if its first window closes and it has period 3. For every $n \geq 3$ there are exactly 9 such words.

Proof. The sums of windows k and $k + 1$ differ by $t_{k+3} - t_k$. If both close, $t_{k+3} \equiv t_k$, so $t_{k+3} = t_k$. Conversely, period 3 and a closed first window give every window the same sum 0. The first window fixes the word: 9 choices (T3). ∎ The hypothesis $n \geq 3$ is needed: for $n = 1$ and 2 there are no windows and the counts are 3 and 9. Status: proven; recomputed for $n = 3$ to 8, and by the judge for $n = 9$ to 16.

Foundations T9 and T10. Let the rewrite R act on a ring, with cyclic indices and values taken modulo 3, by $R(t)_i = -\left(t_{i-1} + t_{i+1}\right)$. A ring is a fixed point of R if and only if every window closes. There are 9 such rings when 3 divides n, and 3 (the constant rings) otherwise. Since $2 \equiv -1 \pmod 3$, each trit becomes the mean of its neighbours. Status: proven; checked by the judge for $n = 1$ to 12. That the fixed points are the eigenforms of the register is read.

4.4 Seams

Foundations T11. Join two closed windows A and B. The seam is closed if and only if $B = A$. Over all 81 ordered pairs: 9 closed seams, 36 with one open window, 36 with two. Status: proven; recomputed.

A window continued in its own order carries no tension. A seam between two different closed windows always carries tension. This is the first appearance of an interface.

5. Addresses and Counts

In short.

- Every nonzero integer has one balanced-ternary address (proven, T12).
- Words and their rotation classes are counted exactly (proven, T13).
- In the Eisenstein plane every digit orbit ends at 0 or at a fixed point; only orbits ending at 0 give a finite address (proven, T14; shares computed).

5.1 One address per integer

Foundations T12. Every nonzero integer has exactly one finite balanced-ternary word without leading zero. Words of k digits give exactly the integers from $-\left(3^k-1\right)/2$ to $\left(3^k-1\right)/2$. Status: proven.

Corollaries. The address of $-Q$ is the mirrored address of Q (swap 1 ↔ T). The sign of a charge is a property of the string. Reading at finite depth is rounding to nearest without any convention. The largest values expressible with n digits, $\left(3^n-1\right)/2$, are $1, 4, 13, 40, 121, \ldots$ The sign of a charge as a property of the string is read.

The uniqueness is equivalent to an identity of formal series that goes back to Euler.[8] The Setun computer (Moscow, 1958) computed in balanced ternary.[9]

5.2 Open words and closed configurations

Foundations T13. Read from a start, there are 3^n words of length n. Read without a start, words are rotation classes. The number of rotation classes of all words is the necklace count

$$g(n)=\frac{1}{n}\sum_{d\mid n}\varphi\left(n/d\right)3^d=3,6,11,24,51,130\quad\left(n=1,\ldots,6\right).$$

[8] G.E. Andrews, "Euler's *De Partitio numerorum*", *Bull. AMS* 44(4), 2007, 561–573.

[9] N.P. Brusentsov and J. Ramil Alvarez, "Ternary Computers: The Setun and the Setun 70", in *Perspectives on Soviet and Russian Computing*, IFIP AICT 357, Springer, 2011.

The Ninth Edition calls these the closed configurations; the count includes open words. The rotation classes of closed words number 1, 2, 5, 8, 17, 46, 105, 278 for $n = 1$ to 8 (recomputed by judge and respondent). Status: proven; known (Burnside's lemma).

5.3 The limit of the address

Foundations T14. In the Eisenstein integers $\mathbb{Z}[\omega]$ take the digit map $z \mapsto \big(z - d\big)/(1 - \omega)$, with $d \in \{-1, 0, 1\}$ the balanced residue of $z = a + b\omega$ ($d \equiv a + b \bmod 3$). Every orbit ends at 0 or at a fixed point $\pm(1 + \omega)$, where the digit repeats as T or 1. The proof uses $\big|z'\big| \leq \big(\big|z\big| + 1\big)/\sqrt{3}$, which makes the norm fall until it is at most 1. The digits give a finite word only to elements whose orbit ends at 0. In the box $\big|a\big|, \big|b\big| \leq 40$ the share ending at a fixed point is 1,788 of 6,561 (27.3 %); for $\big|a\big|, \big|b\big| \leq 100$ it is 16,546 of 40,401 (41.0 %). Larger boxes give 32.2 % (200) and 24.1 % (300); the judge found values between 22 % and 42 % for boxes up to 900. The share oscillates. Status: proven (orbit ends); computed (shares). Whether the share settles is open (IX.3).

6. Two Ladders and the Comma

In short.

- Meetings double; rings triple (proven under hypothesis, T15).
- $2^n \neq 3^k$: the two ladders never meet (proven, T16).
- At closure depth 12 they miss by the Pythagorean comma, 23.46 cents; the miss never vanishes (proven, T17, T18).

6.1 Doubling and tripling

Foundations T15. Merge the strand at each scale into blocks of equal size, each block a meeting (2) or a ring (3). After a merges of meetings and b merges of rings, one coarse passage holds

$$2^a \cdot 3^b$$

passages of the finest scale. Status: proven under hypothesis (equal blocks).

6.2 The ladders never meet

Foundations T16. $2^n \neq 3^k$ for all non-negative integers other than $n = k = 0$. Hence $\log_2 3$ is irrational. Status: proven (even against odd; negative exponents follow by taking reciprocals).

6.3 Closure depths

The depths k at which 3^k comes closer in ratio to a power of 2 than at any smaller depth — that is, at which $\left| k \log_2 3 - n \right|$ reaches a new minimum (best approximations of the second kind) — are the denominators of the convergents of

$$\log_2 3 = \left[1; 1, 1, 2, 2, 3, 1, 5, 2, 23, 2, 2, 1, 1, 55, \ldots\right].$$

Foundations T17. The closure depths are

$$1, 2, 5, 12, 41, 53, 306, 665, 15601, 31867, 79335, 111202, 190537, \ldots$$

Status: proven (Lagrange's theorem on best approximations of the second kind).[10] Recomputed (Appendix A.4); the judge scanned every $k \leq 10^7$ and found the next depth at 10,590,737. In absolute difference $\left|3^k - 2^n\right|$ only $k = 1$ is a record.

6.4 The comma

Foundations T18. At depth 12 the ladders miss by

$$\frac{3^{12}}{2^{19}} = \frac{531441}{524288} = 1.013643,$$

the Pythagorean comma of 23.46 cents. The miss never vanishes. Status: proven.

The comma is the first rest that cannot be removed. It reappears in every later scale as a remainder that passes on.

[10] A.Ya. Khinchin, *Continued Fractions*, University of Chicago Press, 1964, Chapter II, §6.

7. The First Knot, Rotation and Charge

In short.

- The first knot that cannot be undone has three crossings (proven under hypotheses, T19).
- It has a mirror twin: chirality starts here (proven, T20).
- Spin ½ is the return after 4π; charge is a conserved winding number (proven under hypotheses, T21, T22).

This chapter adds one hypothesis: the strand is embedded in three-dimensional space. A crossing in a planar projection has three states: over $(+1)$, under (-1), none (0).

7.1 The trefoil

Foundations T19. The trefoil is the simplest configuration that cannot be undone. It has three crossings. Status: proven under named hypotheses.

The proof is ternary. Three arcs carry three colours. At each crossing the colours are all equal or all different: the window rule of Chapter 3. The number of such colourings is unchanged by the three Reidemeister moves; the unknot admits only the three single-colour colourings, the trefoil nine, so the two differ.[11] Below three crossings every diagram reduces to the unknot.[12]

7.2 Chirality

Foundations T20. The Jones polynomial of the trefoil is $V(t) = t + t^3 - t^4$. Its mirror image gives $V(t) = t^{-1} + t^{-3} - t^{-4}$. The two differ. The first knot is chiral. Status: proven under named hypotheses.[13]

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[11] R.H. Fox and R.H. Crowell, *Introduction to Knot Theory*, Ginn, 1963; Springer GTM 57, 1977.

[12] K. Reidemeister, "Elementare Begründung der Knotentheorie", *Abh. Math. Sem. Univ. Hamburg* 5, 1927, 24–32.

[13] V.F.R. Jones, "A polynomial invariant for knots via von Neumann algebras", *Bull. AMS* 12(1), 1985, 103–111; L.H. Kauffman, "State models and the Jones polynomial", *Topology* 26(3), 1987, 395–407.

7.3 The return after 4π

Foundations T21. If orientation states are unit quaternions and the strand is attached, the strand returns to its initial state after a rotation of 4π, not 2π. The reason is that q and $-q$ give the same rotation, and $\pi_1\big(\mathrm{SO}(3)\big) = \mathbb{Z}/2$. Status: proven under named hypotheses.

This is the rotation property of spin-½ matter (Chapter 14).

7.4 Charge without symmetry

Foundations T22. For field configurations on $\mathbb{R}^3$ with a fixed value at infinity, so that they are maps $S^3 \to S^2$, the Hopf charge $Q \in \pi_3\big(S^2\big) = \mathbb{Z}$ is conserved under every continuous rewrite. Status: proven under named hypotheses.[14] No symmetry argument (Noether) is used. A conserved integer charge follows from continuity alone.

[14] H. Hopf, "Über die Abbildungen der dreidimensionalen Sphäre auf die Kugelfläche", *Math. Ann.* 104, 1931, 637–665.

8. Coupling of the Net

In short.

- The response of the net depends on its state (proven under the stated energy, T23).
- The lever of a free path is -3.94 in three dimensions (proven, T24).
- Lever and coupling are one number (proven under H-R and T24, B15).

8.1 Stiffness as a state function

Foundations T23. Let the energy density of the net be

$$e(n) = g_2/2n^2 + g_3/6n^3 .$$

Then the effective stiffness $g_{\text{eff}} = e''(n)$ at density $n = \bar{n}(1 + \delta)$, with $\bar{g} = e''(\bar{n})$, is

$$g_{\text{eff}} = \bar{g}\,(1 + \gamma\delta), \qquad \gamma = \frac{g_3\bar{n}}{\bar{g}}, \qquad g_2 = \bar{g}(1 - \gamma) .$$

Status: proven (under the stated energy density). This is N4 made explicit: the response of the net depends on its state.

8.2 The lever of a free path

Definition (lever of a count). For a count N with mean κ_1 and cumulants $\kappa_2 > 0$, κ_3, the lever is $\gamma(N) = -\kappa_1\kappa_3/\kappa_2^2$ (Ninth Edition, Part VIII).

Foundations T24. For a free random walk in $d \geq 3$ dimensions with return probability P_d, the number $N \geq 1$ of visits to a place, the first included, is geometric. Its lever is

$$\gamma = -\frac{1 + P_d}{P_d} .$$

With $P_3 = 0.3405373$ this gives $\gamma = -3.9365$.[15] For $d = 4$ and $d = 5$: -6.1759 and -8.3976.

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[15] G.N. Watson, "Three triple integrals", *Quart. J. Math. Oxford* 10, 1939, 266–276; E.W. Montroll, "Random walks in multidimensional spaces", *J. SIAM* 4(4), 1956, 241–260.

Proof. With $q = 1 - P_d$: $\kappa_1 = 1/q$, $\kappa_2 = P_d/q^2$, $\kappa_3 = P_d\big(1 + P_d\big)/q^3$. Hence $-\kappa_1\kappa_3/\kappa_2^2 = -\big(1 + P_d\big)/P_d$. ∎ Status: proven (hypothesis: free random walk); recomputed. The judge obtained $P_3 = 0.340537329551$, $P_4 = 0.193201673225$ and $P_5 = 0.135178609821$.

8.3 Lever and coupling

Whether the lever of the free path is the coupling of the net was open (Foundations IX.1). Chapter 25.7 closes it under two hypotheses: the visit count is that of a free walk on the cubic net (T24), and the energy of the net is the rate function of that count (H-R, Theorem B15). Under that hypothesis $\gamma = -3.9365$ and the stiffness at the reference state is $\bar{g} = \big(1 - P_3\big)^2/P_3 = 1.2771$ in units of the count. Without it the point stays open.

Part II — Physics

9. Motion: Dirac and Nilpotence

In short.

- $E^2 = p^2 + m^2$ is an identity of the nilpotent form (proven, Physics T1).
- In one space dimension it follows from the strand itself (proven under H-D1, B10).
- Mass is read as how often light turns back; in 1+1 dimensions this enters the dispersion exactly (proven under H-D1, B10).

9.1 The input

Dirac's equation of 1928 describes the electron.[16] In natural units it reads $\left(\gamma^\mu p_\mu - m\right)\psi = 0$.

This chapter takes it as input. A derivation of Dirac's equation from N1–N5 without input is open (O6); Chapter 25.2 reduces it in one space dimension.

9.2 Rowlands' form

Rowlands replaces the four gamma matrices by two commuting sets of units: the quaternion units $\mathbf{i}, \mathbf{j}, \mathbf{k}$ (square -1, anticommuting) and vector units carried by the momentum (square $+1$, anticommuting).[17] A scalar imaginary unit i commutes with both. The Dirac operator becomes

$$Q = i\,\mathbf{k}E + \mathbf{i}\,\mathbf{p} + \mathbf{j}m\,.$$

Physics T1 (Nilpotence is the mass shell).

$$Q^2 = \left(E^2 - p^2 - m^2\right) \cdot 1\,.$$

So $Q^2 = 0$ exactly when $E^2 = p^2 + m^2$.

Proof. The three squares give E^2, $-p^2$ and $-m^2$; the middle one uses the vector-unit algebra, in which the momentum term squares to p^2. The three cross terms are anticommutators of two different quaternion units. Each is zero. ∎ Status: proven (an algebraic identity). Dirac's equation is the input only for reading Q as the Dirac operator. Known (Rowlands 2007). Checked exactly in a 4×4 representation by the independent judge; on the mass shell Q is nilpotent with rank 2.

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[16] P.A.M. Dirac, "The Quantum Theory of the Electron", *Proc. R. Soc. A* 117, 1928, 610–624.

[17] P. Rowlands, *Zero to Infinity: The Foundations of Physics*, World Scientific, Singapore, 2007.

9.3 The link to the net

The three units of Q are three floors E, p, m with signature $(+, -, -)$. A closed configuration applied to itself adds nothing: $Q^2 = 0$. The theory reads nilpotence as closure (correspondence C3). The chain is

Dirac (input) → nilpotent form (Rowlands) → $Q^2 = 0 \leftrightarrow$ closure (C3) → $E^2 = p^2 + m^2$ (T1).

The relativistic energy–momentum relation thus sits on the chain. It is reached through one input and one reading (C3).

10. Field: Maxwell's Two Registers

In short.

- Maxwell wrote his field in quaternions: a scalar and a vector register.
- On a flat net that structure is exact (proven under H-Q1, H-Q2, B9).
- The gauge freedom sits in the scalar register (proven under H-Q1, H-Q2, B9).

10.1 The record

Hamilton's operator $\nabla = \mathbf{i}\,\partial_x + \mathbf{j}\,\partial_y + \mathbf{k}\,\partial_z$ acts on a vector with one product. That product has a scalar part (Maxwell's convergence, the negative of the divergence) and a vector part (the curl). Maxwell wrote his grouped equations of 1873 in Cartesian components in Articles 591–619 of the *Treatise* and gave the quaternion form in Article 619.[18] Gibbs and Heaviside later split the one product into dot and cross.[19] The scalar register then disappeared from the standard form.

In Maxwell's text the coefficients K, C and μ are properties of the medium (in the net: of the windings of the strand), with $c^2 = 1/(K\mu)$.

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[18] J.C. Maxwell, *A Treatise on Electricity and Magnetism*, Clarendon Press, Oxford, 1873, Vol. II, Arts. 591–619 (quaternion form in Art. 619) and 784 ff.

[19] J.W. Gibbs, *Elements of Vector Analysis*, New Haven, 1881–84; O. Heaviside, *Electromagnetic Theory*, Vol. I, The Electrician, London, 1893.

10.2 The reading in the net

Maxwell	Net
One product, two readings	Two readings of one closure operation
Potential first, fields as readings	The winding state of the mesh is the object
Free charge	Scalar residue of non-closure, written as a trit
Displacement current	The term that completes closure: total current always closes
Moduli K, C, μ	State functions of the local vacuum (N4)
$c^2 = 1/(K\mu)$	c as a state function
Non-commuting product	Order is orientation (N3); full return after 4π

Status: read. Maxwell's equations are read here, not derived (O5). Chapter 25.1 derives their structure under one hypothesis.

10.3 Why the scalar register is needed

Physics T2. For unit vectors q, a with $c = \cos(q, a)$: $\left|q + a\right|^2 - \left|q - a\right|^2 = 4c$.

Physics T3. With pure quaternions every term of a triple product reduces to dot products or to a determinant. The determinant carries the orientation and sits in the scalar part. Orientation is lost when the scalar register is dropped.

Physics T4 (Ring measure). For unit quaternions $D_1, \ldots, D_k$ put $B = \frac{1}{k}\sum D_i D_i^{\mathsf{T}}$ and $R_Q = \lambda_1(B)$. Then $1/4 \le R_Q \le 1$, and R_Q is unchanged when any D_i is replaced by $-D_i$.

Status of T2–T4: proven (no hypothesis is used). That the sign invariance in T4 is the double cover of Chapter 7 is read.

11. Measure: Units from Hydrogen

In short.

- Length, time and mass map to Larson's space and time (proven as a map, Physics T5; the reading is input).
- c, h and G are conversions (N7).
- Only ratios are targets: α, m_p/m_e and a short list.

11.1 The model has no units

The quantities of the net are ratios: winding sums, densities relative to a reference. There is no $\hbar$ in the model. SI numbers are conversions made afterwards, for comparison with instruments.

By N7 this is an axiom, not a convenience. A constant with a unit is a conversion between two human references. Only dimensionless numbers are properties of the net. This is also the position of Duff in the debate on the number of fundamental constants: none of the dimensionful constants is fundamental.[20] The targets of a derivation are therefore ratios (Chapter 25.9):

Ratio	Value	Status
Fine-structure constant α	1/137.036	open (O7)
m_p/m_e	1836.15	open (O3)
Gravity to electric force, two protons	8.09×10^{-37}	reduced to $\left(m_p/m_{\mathrm{Pl}}\right)^2/\alpha$ (25.9)
$a_0/\left(cH_0\right)$	about $1.11/2\pi$ measured	read as $1/2\pi$ (C5)

[20] M.J. Duff, L.B. Okun and G. Veneziano, "Trialogue on the number of fundamental constants", *JHEP* 2002(03), 023, arXiv:physics/0110060.

11.2 Larson's ladder of dimensions

Larson reads space S and time T as the two aspects of one motion.[21] Motion is S/T. Energy is T/S. Mass is T^3/S^3.

Physics T5 (The bridge). The map $\varphi(x, y, z) = (x - 3z,\ y + 3z)$ sends the SI dimension $L^x T^y M^z$ to $S^{x-3z} T^{y+3z}$. It sends speed to S/T, energy to T/S, momentum to T^2/S^2 and mass to T^3/S^3. Its kernel is generated by ML^3/T^3, also over the integers. The map covers only length, time and mass; Larson's reading of these dimensions is input. Status: proven (the map); input (the reading).

Planck's relation $E = h\nu$ then gives $h = T^2/S$.

11.3 The conversion units

The units are fixed by hydrogen. Inputs are the CODATA 2018 values.[22]

Unit	Definition	Value
R_H	$R_\infty / \left(1 + m_e/m_p\right)$	10,967,758.340 m^{-1}
S_0	$1/(2R_H)$	$4.55881671 \times 10^{-8}$ m
T_0	S_0/c	$1.52065757 \times 10^{-16}$ s
E_0	$h/T_0 = 2hcR_H$	27.1965745 eV

E_0 is the Hartree energy of hydrogen with its reduced mass. On the ring ladder the layer at depth n has length $3^n S_0$. At depth 2 this is $9S_0 = 410.29$ nm, the Balmer Hδ line. This holds by construction of S_0 and is not an independent agreement (Appendix A.5).

Note. The Ninth Edition does not take hydrogen as the start of the derivation. Hydrogen fixes only the conversion to SI.

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[21] D.B. Larson, *The Structure of the Physical Universe*, North Pacific Publishers, Portland, 1959.

[22] E. Tiesinga et al., "CODATA recommended values of the fundamental physical constants: 2018", *Rev. Mod. Phys.* 93, 2021, 025010.

12. Loss and the Second Law

In short.

- Loss has an address: entropy production is non-negative at every place (known, Physics T6, under the de Groot–Mazur hypotheses).
- Entropy production is read as located closure (read).

12.1 Loss has an address

Physics T6. Under local equilibrium per mesh, local balance equations and the second law for every sub-volume, the entropy production is

$$\sigma = \sum_i J_i X_i \geq 0$$

at every location. In the linear regime $J = LX$ with symmetric, positive semidefinite L. The terms are sign-definite in the eigenchannels of L. In coupled channels a single $J_i X_i$ can be negative. The symmetry of L is Onsager reciprocity, a further input; the local second law is a hypothesis. Status: known (de Groot–Mazur).[23]

12.2 Reading

Every irreversible discharge occurs at a mesh with an address. Loss is bookkeeping on the net, not a leak out of it. In the language of N2: an open window keeps tension; a discharge closes part of it at a definite place.

12.3 Temperature and heat

Temperature, heat capacity and the laws of thermodynamics are taken from the literature as input. The net contributes the reading of entropy production as located closure. Status: read.

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[23] S.R. de Groot and P. Mazur, *Non-Equilibrium Thermodynamics*, North-Holland, Amsterdam, 1962.

13. Mechanics and Gravitation

In short.

- A window that continues its own order carries no tension: inertia (read).
- Charge is conserved by topology, not by symmetry (proven under hypotheses).
- Below about 1.2×10^{-10} m s^{-2} galaxy rotation curves flatten (input). The net reads the threshold as $cH_0/2\pi$, one turn per mesh (read, C5; the 2π is not derived; P3 known).

13.1 Inertia

Newton's first law states that a body keeps its state of motion unless acted upon. In the net: a window continued in its own order carries no tension (Foundations T11). A closed winding that continues in its own order needs nothing from outside. Status: read.

13.2 Conservation

In the standard account conservation laws follow from symmetries (Noether). In the net one conservation law follows from topology alone: the Hopf charge (Foundations T22). Energy and momentum conservation remain input. Status: charge conserved, proven under named hypotheses; energy and momentum, input.

13.3 The acceleration threshold

Rotation curves of galaxies flatten below a characteristic acceleration of about 1.2×10^{-10} m s^{-2}.[24] The net reads this threshold as one geometric turn per mesh (correspondence C5):

$$a_0 = \frac{cH_0}{2\pi}\,.$$

H_0 (km s^{-1} Mpc^{-1})	Source	a_0 (m s^{-2})	Below 1.2×10^{-10} by
67.4	Planck 2018	1.04×10^{-10}	13 %

[24] F. Lelli, S.S. McGaugh and J.M. Schombert, "SPARC", *Astron. J.* 152, 2016, 157; S.S. McGaugh, F. Lelli and J.M. Schombert, *Phys. Rev. Lett.* 117, 2016, 201101.

H_0 (km s⁻¹ Mpc⁻¹)	Source	a_0 (m s⁻²)	Below 1.2×10^{-10} by
70.0	Reference value	1.08×10^{-10}	10 %
73.0	Distance ladder	1.13×10^{-10}	6 %

The closeness of a_0 to $cH_0/2\pi$ is a known coincidence in the literature.[25] The measured threshold carries a systematic uncertainty of about $\pm 0.24 \times 10^{-10}$ m s⁻²; all three values of the table fall inside it.[26] The theory adds the reading of 2π as one turn per mesh. Status: read (I3); the 2π turn is not derived. It becomes a test only when the theory fixes H_0 or the turn independently (O8).

13.4 The edge of the solar winding

Prediction P3. The solar winding ends where the internal acceleration meets the background:

$$\frac{GM_\odot}{r^2} = a_0 \quad \Rightarrow \quad r_{\text{edge}} = \sqrt{GM_\odot/a_0} \approx 7,400 \text{ AU}.$$

The value 7,400 AU holds for $H_0 = 70$; for H_0 from 67.4 to 73 the range is 7,250–7,540 AU. With the measured threshold 1.2×10^{-10} m s⁻² the edge lies at 7,030 AU (Appendix A.6). This radius is the known MOND transition radius of the Sun, about 7,100 AU.[27] The external field of the Galaxy is not treated here. Status: known; the edge of a winding is a reading (read).

13.5 No dark-matter particle

Prediction P4. No context-independent dark-matter particle will be detected. A collective excitation that tracks the state variable does not count as such a particle. Status: read; as a prediction it has no operational criterion and no time horizon, so it cannot yet be tested (GAP).

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[25] M. Milgrom, *Astrophys. J.* 270, 1983, 365–370; M. Milgrom, "The modified dynamics as a vacuum effect", *Phys. Lett. A* 253, 1999, 273–279.

[26] F. Lelli, S.S. McGaugh and J.M. Schombert, "SPARC", *Astron. J.* 152, 2016, 157; S.S. McGaugh, F. Lelli and J.M. Schombert, *Phys. Rev. Lett.* 117, 2016, 201101.

[27] L. Blanchet and J. Novak, "Testing MOND in the Solar System", arXiv:1105.5815, 2011 ($r_0 \simeq 7100$ AU).

13.6 General relativity

General relativity is not derived in this book. Of its classical tests, the deflection of light follows in Chapter 25.8 under one hypothesis. The perihelion shift of Mercury and the gravitational redshift remain external measurements. The net reads gravity through the state variable χ (identifications I2–I4). Status: open, except as stated in 25.6 and 25.8.

Where N4 parts from general relativity. General relativity assumes the Einstein equivalence principle: universality of free fall, and local laws that are the same at every place and time (local position invariance). N4 says the response of the net is a state function; universality is the limiting case where the state does not vary. Within the measured range the two agree:

Test	Result	Source
Redshift, eccentric Galileo satellites	deviation $(+0.19 \pm 2.48) \times 10^{-5}$	Delva et al. 2018
Equivalence principle, Ti against Pt	$\eta = (-1.5 \pm 2.3 \pm 1.5) \times 10^{-15}$	MICROSCOPE 2022
Drift of α, two atomic clocks	$\dot{\alpha}/\alpha = (-1.6 \pm 2.3) \times 10^{-17}$ per year	Rosenband et al. 2008

The difference lies outside that range: at very low acceleration (13.3) and across cosmic distance. A spatial dipole in α was reported at 4.2σ;[28] instrumental wavelength distortions were later shown to be able to produce shifts of this size, which significantly weakens the evidence (fully for the VLT data, partly for the Keck data).[29] Prediction P5(ii) makes the point testable: any dipole in α must vanish after regression on the state variable. Status: read; registered prediction. Section 25.6 derives the sign of the static coupling (Theorem B14) and states what remains for Newton's $1/r$, for light deflection and for the tensor part.

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[28] J.K. Webb et al., "Indications of a spatial variation of the fine structure constant", *Phys. Rev. Lett.* 107, 2011, 191101, arXiv:1008.3907.

[29] J.B. Whitmore and M.T. Murphy, "Impact of instrumental systematic errors on fine-structure constant measurements with quasar spectra", *Mon. Not. R. Astron. Soc.* 447, 2015, 446–462.

14. Light, Relativity and the Quantum

In short.

- Light moves one step per tick (N6).
- Light bends by refraction, $4GM/c^2b$ (proven under N6, H-S and the Newtonian potential, both input; B16).
- Spin ½ is the return after 4π (proven under the quaternion hypothesis, T21; identification read, C2).

14.1 The speed of light

In SI the speed of light is fixed by definition at 299,792,458 m s^{-1}.[30] In the net, by N6, light moves exactly one step per tick. By N7 the SI value is a conversion between human references, not a property of the net. The Ninth Edition calls *c* a state function. Under N6 and N7 this can mean that the ratio between two windings shifts, or that the reference speed $(1-\varphi)/(1+\varphi)$ near a source differs from one (Chapter 25.8); the local speed stays one step per tick. Such a shift is measurable: the mean solar day lengthens on average by about 1.8 ms per century against uniform time (720 BC to AD 2015).[31] That is a changing ratio of windings, not a changing speed of light. Status: assumed (one step per tick is N6); input (1.8 ms per century); read (reading of the Ninth Edition statement).

14.2 Special relativity

The invariant relation $E^2 = p^2 + m^2$ follows from Physics T1 under the Dirac input, and in one space dimension from the strand itself (Chapter 25.2). The sign pattern $(+,-,-)$ of the three floors of Q matches the signs of $E^2 - p^2 - m^2$; it is not the signature $(+,-,-,-)$ of the spacetime interval. Status: proven (relation), read (sign pattern).

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[30] BIPM, *The International System of Units (SI)*, 9th ed., 2019, §2.2 and §2.3.1.

[31] F.R. Stephenson, L.V. Morrison and C.Y. Hohenkerk, "Measurement of the Earth's rotation: 720 BC to AD 2015", *Proc. R. Soc. A* 472, 2016, 20160404.

14.3 Spin

Spin-½ is the rotation label of Foundations T21: return after 4π. Status: proven under the quaternion hypothesis; the identification with the electron spin is read (C2).

14.4 Planck's constant

In the dimensional ladder $h = T^2/S$ (Chapter 11). The numerical value of h is input; it fixes the SI conversion.

14.5 The fine-structure constant

Prediction P1. The net reads α as a function of context: $\Delta\alpha/\alpha = \beta\Delta\chi$. For the white dwarf G191-B2B, with $\Delta\chi_\Phi = GM/(Rc^2) = 5.30 \times 10^{-5}$ and $\beta = \alpha/4\pi = 5.807 \times 10^{-4}$ (input; the factor β is not derived and sets the whole size of the prediction):

$$\frac{\Delta\alpha}{\alpha} \approx 3.08 \times 10^{-8}\,.$$

The published stellar parameters give 3.14×10^{-8}.[32] The measured values are $\left(6.36 \pm 0.33_{\text{stat}} \pm 1.94_{\text{sys}}\right) \times 10^{-5}$ and $\left(4.21 \pm 0.47_{\text{stat}} \pm 2.35_{\text{sys}}\right) \times 10^{-5}$ for two sets of laboratory wavelengths. The uncertainty of about 2×10^{-5} lies three orders of magnitude above the prediction. It cannot be decided with present data. Status: read; a registered prediction, not yet testable.

The value of α itself is input (O7).

14.6 Forbidden outcomes

Prediction P5. The theory forbids (i) a quantized spin-2 graviton and (ii) a residual dipole in α after regression on the state variable. Part (i) cannot be tested with any foreseeable experiment. Status: read; registered prediction.

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[32] J. Hu, J.K. Webb, T.R. Ayres et al., "Measuring the fine structure constant on a white dwarf surface", *Mon. Not. R. Astron. Soc.* 500, 2021, 1466–1475, doi:10.1093/mnras/staa3066.

15. Particles and Nuclei

In short.

- Stable particles are closed windings (read, C4); the electron is one closed loop of light (identified, I1).
- The proton is a closure of three windings with charges in thirds (read).
- Only zero-triality states are observed; for up to three constituents this is exactly the closure rule mod 3 (translated).
- Binding energy is released tension (read).

15.1 The electron

The theory identifies the electron with the Williamson–van der Mark configuration: a photon closed on itself in a double loop (I1).[33] The double loop matches the return after 4π. Status: identified.

15.2 Stable particles are closed windings

Correspondence C4: stable particles are closed windings. Unstable particles are windings that do not close at their scale and pass on. This reads lifetime as the persistence of a closure. Status: read.

15.3 The mass spectrum

The masses of the particles, including the proton–electron ratio $m_p/m_e = 1836.15$, are not yet derived. The same holds for the electric charge as a number (O3) and for α (O7). Status: open.

15.4 Nuclei

The nuclear binding energies, the magic numbers and radioactive decay are not derived in this book. They are taken as input where chemistry needs them. Section 15.7 gives their reading as released tension. Status: open.

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[33] J.G. Williamson and M.B. van der Mark, "Is the electron a photon with toroidal topology?", *Annales de la Fondation Louis de Broglie* 22(2), 1997, 133–160.

15.5 The proton as a closure of three

This section translates four measured facts about the proton into the net. It uses no term from particle physics in the reading itself.

Measured fact	Reading in the net	Status
Deep inelastic scattering on a proton shows point-like constituents; three of them (the valence constituents) carry its net charge and baryon number	The proton is a closure of three windings, not one loop	Read
The charges of the three are $+2/3$, $+2/3$ and $-1/3$ of the elementary charge; the sum is $+1$	Charges in thirds: the trinity divided by three	Read
None of the three has been observed alone	N2: only what closes persists; one part alone is an open window	Read
Only combinations with (number of parts) minus (number of anti-parts) divisible by 3 are observed	The closure rule $x + y + z \equiv 0 \pmod 3$	Translated

The last row is exact for up to three constituents under the map part → +1, anti-part → −1, empty place → 0: the nine closed windows are then the vacuum, the baryon, the antibaryon and the six ordered part–anti-part pairs. Observed states with four or five constituents (tetraquarks, pentaquarks) need the rule on a longer word. In the literature the rule is stated as follows: the

colour group SU(3) has the centre $\mathbb{Z}_3$, and observed states have zero "triality".[34] In QCD it follows from the gauge group SU(3); in the net the same arithmetic is the closure axiom N2. The zero-triality rule is not itself the condition for confinement: a gauge group with trivial centre, G(2), also confines.[35] In particle physics the three parts are called quarks, the closure between them the strong interaction, and its carriers gluons.

Not derived: why the charges are exactly $2/3$ and $1/3$; the mass of the proton; why the electron is one loop and the proton three windings. Status: open (O3).

15.6 Mass and weight as two counts

Weighing is comparison with a reference. Since the revision of the SI in 2018–2019 the kilogram is fixed by the Planck constant, and so by a frequency.[36] Under N7 a mass is a ratio of counts.

Measured property	Count in the net	Where
Inertia: how hard a body is to set in motion	How often the light location turns back in the loop; a shorter loop turns back more often	B10 (θ), I1
Weight: how strongly a body is attracted	The shift of the visit density of the strand around the loop	B14 (source s)

[34] K. Holland, P. Minkowski, M. Pepe and U.-J. Wiese, "Exceptional confinement in G(2) gauge theory", *Nucl. Phys. B* 668, 2003, 207–236, arXiv:hep-lat/0302023 (centre $\mathbb{Z}(3)$ and triality); IJCLab, *Introduction to QCD*, NPAC course 5, 2022 (quark charges $2/3$ and $-1/3$; baryons of three quarks). G(2) has a trivial centre and confines without the Z(3) rule. Point-like constituents: E.D. Bloom et al. and M. Breidenbach et al., *Phys. Rev. Lett.* 23, 1969, 930 and 935; free quarks: Particle Data Group, "Searches for free quarks".

[35] K. Holland, P. Minkowski, M. Pepe and U.-J. Wiese, "Exceptional confinement in G(2) gauge theory", *Nucl. Phys. B* 668, 2003, 207–236, arXiv:hep-lat/0302023 (centre $\mathbb{Z}(3)$ and triality); IJCLab, *Introduction to QCD*, NPAC course 5, 2022 (quark charges $2/3$ and $-1/3$; baryons of three quarks). G(2) has a trivial centre and confines without the Z(3) rule. Point-like constituents: E.D. Bloom et al. and M. Breidenbach et al., *Phys. Rev. Lett.* 23, 1969, 930 and 935; free quarks: Particle Data Group, "Searches for free quarks".

[36] BIPM, "SI base unit: kilogram", bipm.org; 26th CGPM, November 2018.

The ratio of weight to inertia is the same for titanium and platinum to 10^{-15} (MICROSCOPE, 13.6). In the net both are counts of the same loop. That they are equal is not derived ("one sign of mass", 25.6). Status: read; open.

15.7 Released tension

A closed whole weighs less than its parts taken apart. A hydrogen atom is 13.6 eV lighter than a free proton and a free electron. A helium-4 nucleus is 28.3 MeV, or 0.75 %, lighter than two free protons and two free neutrons (Appendix A.21). The difference leaves as radiation and as motion of the products (for helium formed in stars, also as neutrinos). The literature calls it binding energy.

In the net (N2): what does not close passes on as tension. When separate loops form one closure, part of the tension no longer has to be carried and passes on as light. The closed whole carries less. "Binding energy" is the tension released at a closure. Nothing binds; something closes, and the excess passes on.

The proton is the opposite case. The current masses of its three parts (PDG: $m_u \approx 2.2$ MeV, $m_d \approx 4.7$ MeV) add to about 1 % of its mass.[37] Almost all of its mass sits in the closure itself: in the circulation of the three windings. Status: read. The amounts (13.6 eV, 28.3 MeV, the proton mass) are not derived (O3).

15.8 What this part has reached

The chain from the first distinction reaches the relativistic mass shell, conserved integer charge, spin-½ rotation, located entropy production (under the de Groot–Mazur hypotheses) and a dimensional ladder. Each of these holds by proof under named inputs. Maxwell's field, gravity and the particle spectrum are read, not derived. These are the open links of physics in the theory.

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[37] Particle Data Group, *Review of Particle Physics*, quark masses ($\overline{\text{MS}}$ at 2 GeV): $m_u = 2.16$ MeV, $m_d = 4.67$ MeV; sum of valence current masses 8.99 MeV, 0.96 % of m_p.

Part III — Chemistry

16. The Atom

In short.

- Shell n holds $2n^2$ states (proven under input, B1).
- The factor 2 is the double cover of spin ½ (read).

16.1 The input

The energy levels of hydrogen follow the Rydberg formula. With the reduced-mass constant R_H of Chapter 11:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right).$$

The formula is input from spectroscopy and quantum mechanics.[38] In net units the ground-state binding energy is $E_0/2 = 13.598$ eV.

16.2 The Balmer lines

Transition	Computed vacuum wavelength
$3 \to 2$ (Hα)	656.470 nm
$4 \to 2$ (Hβ)	486.274 nm
$5 \to 2$ (Hγ)	434.173 nm
$6 \to 2$ (Hδ)	410.294 nm

The Hδ line equals $9S_0$, the length of ring depth 2 (Chapter 11). This holds by construction of S_0. Calculations in Appendix A.5. Status: proven under input (Rydberg formula).

16.3 The shell

The states of an electron in an atom carry four labels: $n \geq 1$; $0 \leq l < n$; $-l \leq m \leq l$; and two spin states. These labels are input from quantum mechanics.

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[38] H.A. Bethe and E.E. Salpeter, *Quantum Mechanics of One- and Two-Electron Atoms*, Springer, Berlin, 1957.

Theorem B1 (Shell capacity). Shell n holds $2n^2$ states.

Proof.

$$2\sum_{l=0}^{n-1}\big(2l+1\big)=2n^2\,.$$

∎ Status: proven under input (the labels). Values: 2, 8, 18, 32.

Reading. The factor 2 is the pair of states of the double cover (Foundations T21). Two electrons with opposite spin in one orbital form a meeting $x, -x$: a closure with carry 0 (Foundations T7.1). The exclusion principle then says that one orbital holds at most one meeting. Status: read.

17. The Periodic Table

In short.

- The periods have lengths 2, 8, 8, 18, 18, 32, 32 (proven under input, B2).
- Each length is a doubled square.
- A closed shell carries no tension: the noble gases (read).

17.1 Filling order

Shells fill in the order of increasing $n + l$, and for equal $n + l$ in order of increasing n. This is the Madelung rule. It is an empirical input.[39] Some ground states deviate from it, for example chromium and copper.

17.2 The periods

Theorem B2 (Period lengths). Under the Madelung order the periods have lengths

$$2,\ 8,\ 8,\ 18,\ 18,\ 32,\ 32,$$

with sum 118.

Proof. A period starts where a new s subshell starts. Count $2\big(2l + 1\big)$ states per subshell between two starts (Appendix A.7). ∎ Status: proven under input (Madelung order).

The sum 118 equals the number of named elements, from hydrogen to oganesson.[40]

17.3 The doubled squares

Each period length is a doubled square, $2m^2$, with $m = 1, 2, 2, 3, 3, 4, 4$. Every square after the first occurs twice. In the net: the factor 2 is the meeting, the square is the count of B1. The repetition is a pair of passes over one depth. Status: read.

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[39] E. Madelung, *Mathematische Hilfsmittel des Physikers*, 3rd ed., Springer, Berlin, 1936.

[40] IUPAC, *Periodic Table of the Elements*, version of 4 May 2022, iupac.org.

17.4 Closed shells

The noble gases close their outer shell. A closed shell has no open window: it carries no tension and passes nothing on. This is the low reactivity of helium, neon and argon. It is not absolute: argon forms HArF and xenon forms XeF_2. Atoms with open shells carry tension; a bond closes it. Status: read.

18. The Chemical Bond

In short.

- A bond is a meeting: a closure with carry 0 (read).
- The sum of valences is even (proven, B3).
- Rings and extra bond orders count as $B - N + 1$ (proven under the valence hypothesis, B4); two mirror forms at a tetrahedral atom (proven under input, B5).

18.1 The bond as a meeting

A covalent bond is a shared electron pair. In the net a pair of opposite spins is a meeting: a closure with carry 0. A bond closes two open windows, one at each atom. Status: read.

18.2 The parity rule

Describe a molecule as a connected graph. Atoms are vertices. Bonds are edges with integer order. Let v_a be the number of bonds at atom a, counted with order.

Theorem B3 (Parity). For every such molecule

$$\sum_a v_a = 2B,$$

where B is the number of bonds counted with order. Hence the valence sum is even.

Proof. Every bond has two ends. ∎ Status: proven (graph theory).[41]

Consequence. If the usual valences of the atoms in a formula add to an odd number, at least one electron stays unpaired. The molecule is a radical. Examples: nitric oxide NO (3 + 2 = 5) and nitrogen dioxide NO_2 (3 + 2 + 2 = 7) are radicals.[42] In the net: an odd sum leaves one window open.

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[41] L. Euler, “Solutio problematis ad geometriam situs pertinentis”, 1736; the degree-sum identity is in every graph-theory text, e.g. F. Harary, *Graph Theory*, Addison-Wesley, 1969, Theorem 2.1.

[42] N.N. Greenwood and A. Earnshaw, *Chemistry of the Elements*, 2nd ed., Butterworth-Heinemann, 1997, Chapter 11.

Limit. The rule is necessary, not sufficient. Molecular oxygen O_2 has an even sum (2 + 2) and still has two unpaired electrons in its ground state. Valence counting does not see this. The ground state of O_2 requires the orbital input of quantum chemistry. Status: open in the net.

18.3 Rings and multiple bonds

Theorem B4 (Ring and π count). For a connected molecule with N atoms and B bonds counted with order,

$$R + \Pi = B - N + 1,$$

where R is the number of independent rings and Π the number of extra bond orders (one for each double bond, two for each triple bond).

Proof. A spanning tree of N vertices has $N - 1$ edges. Every further edge closes one independent cycle in the multigraph. A double bond is a two-edge cycle; a triple bond gives two. ∎ Status: proven.[43]

In formula terms, for C, H, N, O and halogens X, with the valences C 4, N 3, O 2, S 2, H and X 1 (hypothesis):

$$R + \Pi = C - \frac{H + X}{2} + \frac{N}{2} + 1\,.$$

With higher valences, such as S(VI) or P(V), the same formula gives the degree of unsaturation, not the structural count of rings and multiple bonds.

18.4 Worked examples

The molecular formulas are those in PubChem.[44] Calculations in Appendix A.8.

All eight valence sums are even, as B3 requires.

Compound	CID	Formula	Valence sum	B	$R + \Pi$	Structure

[43] F. Harary, *Graph Theory*, Addison-Wesley, 1969, Chapter 4 (cycle rank).

[44] PubChem compound records CID 962, 280, 297, 222, 702, 241, 5793 and 2519, pubchem.ncbi.nlm.nih.gov. The CIDs of benzene (241) and caffeine (2519) were cross-checked against independent compound registries.

Compound	CID	Formula	Valence sum	B	$R + \Pi$	Structure
Carbon dioxide	280	CO_2	8	4	2	two C=O
Methane	297	CH_4	8	4	0	saturated
Ammonia	222	NH_3	6	3	0	saturated
Ethanol	702	C_2H_6O	16	8	0	saturated
Benzene	241	C_6H_6	30	15	4	1 ring, 3 π
Glucose	5793	$C_6H_{12}O_6$	48	24	1	1 ring
Caffeine	2519	$C_8H_{10}N_4O_2$	58	29	6	2 rings, 4 π

Glucose in its open-chain form has one C=O instead of the ring; the count stays 1.

18.5 Rings: three and six

The smallest ring in the register has three steps (Foundations T7). In chemistry the smallest carbon ring, cyclopropane, also has three atoms. It carries high ring strain. Six-membered rings, such as those of benzene and glucose, are the common low-strain rings. In the net six is a meeting of rings: $2 \cdot 3$. Status: read. Ring strain values are input.

18.6 Chirality

Theorem B5 (Two mirror forms). An atom with four different substituents at the corners of a tetrahedron has exactly two arrangements that cannot be rotated into each other. They are mirror images.

Proof. There are $4! = 24$ ways to place four different groups. The rotations of a tetrahedron form a group of order 12. Each rotation class therefore holds 12 arrangements, giving $24/12 = 2$ classes. A reflection maps one class onto the other. ∎ Status: proven under input (tetrahedral geometry).

The first knot is also chiral (Foundations T20). In the net, chirality appears first in the trefoil and returns in the tetrahedral carbon. Status: read.

19. All Compounds

In short.

- Electron parity is a proven rule (B7); charge closure is proven under the oxidation-state table (B8).
- 1,183 compounds were checked against these rules (computed, App. C).
- The number of bond graphs that satisfy B3 grows without bound (known); how many are stable compounds is open.

19.1 The catalogue

PubChem is the largest free catalogue of chemical structures. On 12 September 2024 it held 118,596,691 compounds: unique structures extracted from contributed substance records.[45] The 2025 update reports 119 million compounds from more than 1,000 data sources.

19.2 What holds for every compound

The theorems of Chapter 18 hold for every compound in the catalogue that has a defined bond graph with integer bond orders:

1. **B3:** for every entry with an integer bond graph, the valence sum is twice the bond count. An odd sum of the usual valences marks an open window: a radical or a charged species.
2. **B4:** rings plus extra bond orders equal $B - N + 1$.
3. **B5:** every tetrahedral centre with four different neighbours admits exactly two mirror arrangements.

These are counting rules. They hold for every entry that has an integer bond graph, because they follow from the shape of a graph. They have not been run over the catalogue itself. Status: proven.

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[45] S. Kim et al., "PubChem 2025 update", *Nucleic Acids Res.* 53(D1), 2025, D1516–D1525, Table 1; the 2023 update reported 111,892,547 compounds (*Nucleic Acids Res.* 51(D1), 2023, D1373–D1380).

19.3 What does not hold for every compound

The individual properties of a compound — its melting point, its spectrum, its reactivity, its toxicity — are measurements. PubChem stores them per record. The net does not derive them one by one. Status: open.

An honest statement of scope therefore reads: the net supplies the closure rules that every compound obeys; the catalogue supplies the values that each compound has.

19.4 The number of possible compounds

The number of bond graphs that satisfy B3 grows without bound with the number of atoms. The alkanes C_nH_{2n+2} alone have 1, 1, 1, 2, 3, 5, 9, 18, 35, 75 structural isomers for $n = 1$ to 10, and the count keeps growing.[46] Catalogued chemistry is a small sample of what closes. Status: known (unbounded growth); the share of these graphs that are stable compounds is open.

19.5 Two further closure rules

Two rules apply to every formula, not only to molecules with a bond graph.

Theorem B7 (Electron parity). Let Z_a be the atomic numbers of the atoms in a formula unit and q its charge. If

$$n_e = \sum_a Z_a - q$$

is odd, at least one electron is unpaired.

Proof. Paired electrons come in meetings of two. An odd count cannot be split into pairs. ∎ Status: proven. In the net: an odd count leaves one window open.

Theorem B8 (Charge closure). A formula unit with charge q closes by charge transfer only if its atoms admit oxidation states s_a with

$$\sum_a s_a = q\,.$$

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[46] OEIS A000602, number of alkanes C_nH_{2n+2} (structural isomers); the values for n = 1–10 are standard.

Proof. Oxidation states are defined so that their sum equals the charge. A formula without such an assignment, within the known range of each element, cannot be read as a closure by transfer. ∎ Status: proven under input (the table of known oxidation states).[47] In the net this is the meeting of plus and minus at the scale of the formula, with the conserved charge of Foundations T22.

19.6 The test on the Wikipedia lists

The rules B4, B7 and B8 were applied to every compound that could be read from two Wikipedia lists on 6 November 2026.[48]

Item	Count
Inorganic entries read	503
Organic entries read	680
Total	1,183

Coverage. The reading tool returns at most about 61,000–71,000 characters per page. The inorganic list was read from actinium to the fluorine compounds, plus the complete list of other fluorides. The organic dictionary was read from one carbon atom to C_{21}. The remaining parts of both pages could not be read with the tools available. CAS registers more than 204 million substances.[49] The test therefore covers a sample, not all known compounds.

Results, inorganic (503).

Charge closure (B8)	Count
Closes with common oxidation states	412
Closes with rarer oxidation states	61

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[47] S.P. Ong et al., "Python Materials Genomics (pymatgen)", *Comput. Mater. Sci.* 68, 2013, 314–319; oxidation-state ranges as tabulated in that library.

[48] Wikipedia, "List of inorganic compounds" and "Dictionary of chemical formulas", en.wikipedia.org, read 6 November 2026.

[49] CAS Registry Number, Wikipedia, en.wikipedia.org, read 6 November 2026; the CAS site itself states more than 290 million substances, including sequences (cas.org/cas-data/cas-registry).

Charge closure (B8)	Count
Closes only with mixed valence	9
No closure with the pymatgen table	21

In this count an oxidation state of 0 is allowed only for an element standing alone. The split depends on the table of oxidation states. The independent judge used a wider table, with all reported states, and found 486 integer closures, 15 with mixed valence, one (HArF) that needs Ar at 0, and one without closure (CeMg).

The 21 entries without closure in the pymatgen table fall in four groups: intermetallic compounds such as CeAl and ErAu (10); boron-rich compounds such as CaB_6, B_6O and $Cs_2B_{12}H_{12}$ (8); the noble-gas compound HArF; and calcium hypochlorite chloride $CaOCl_2$, in which chlorine has two states (+1 and −1) whose average is 0. The last entry, H_2SbF_6, is a printing error in the source; the acid is $HSbF_6$, which closes. A failure of B8 in one table is therefore not proof that a compound binds without charge transfer. Ring and band closure (Chapter 25.3) give a reading of metallic bonding; cluster bonding is not read in the net in this edition. Status: open.

The class of 127 inorganic entries built only from non-metals, noble gases and the metalloids B, Si, Ge, As, Sb and Te contains four odd electron counts: ClO_2, ClO, ClO_3 and the misprinted H_2SbF_6. The first three are known radicals; ClO_3 is a radical as a gas-phase monomer and forms Cl_2O_6 in the condensed phase.[50] B7 identifies them without any further input.

Results, organic (680). 675 entries have an even electron count. Of the five odd counts, three are metal-containing species with an unpaired electron, among them the silver(II) complex. The other two are errors in the source: furosemide is printed as $C_{12}H_{10}ClN_2O_5S$, while its formula is $C_{12}H_{11}ClN_2O_5S$;[51] and TDBzcholine is a cation printed without its charge. For 635 molecules B4 gives $R + \Pi$. In 633 cases it is a whole number of at least zero; the two exceptions are the same two source errors. Cubane gives $R + \Pi = 5$: its five independent rings. Every unbranched alkane gives 0.

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[50] N.N. Greenwood and A. Earnshaw, *Chemistry of the Elements*, 2nd ed., Butterworth-Heinemann, 1997, Chapter 17 (oxides of chlorine).

[51] *The Merck Index Online*, monograph “Furosemide”, Royal Society of Chemistry; PubChem CID 3440.

Source errors found by the rules.

Entry as printed	Rule	Correct formula
H_2SbF_6, hexafluoroantimonic acid	B7, B8	$HSbF_6$
$C_{12}H_{10}ClN_2O_5S$, furosemide	B7, B4	$C_{12}H_{11}ClN_2O_5S$
$C_{14}H_{17}F_3N_3O_2$, TDBzcholine	B7	cation, charge +1
$CuSO_4$, “copper(I) sulfate”	B8 with the named state	Cu_2SO_4
$Eu(CO_3)_3$, “europium(III) carbonate”	B8 with the named state	$Eu_2(CO_3)_3$

Limits. The rules test whether a formula can close. They do not show that it is stable, and they do not catch every error. For example, the source prints benzoyl peroxide as $C_{14}H_{10}O_{14}$ instead of $C_{14}H_{10}O_4$; oxygen does not change $R + \Pi$ or the parity of a neutral molecule, so the rules do not see it. A second example: the source prints europium(II) sulfide as EuS_2 instead of EuS; EuS_2 closes with sulfur at −1 (a persulfide), so B8 does not see it either.

The complete table is in Appendix C.

20. Reactions and Energy

In short.

- Atoms keep their addresses; only meetings change (read).
- Reaction heat does not depend on the path (proven under input, B6).
- Charge is conserved in every redox step (measured; read as T22 at the scale of the molecule).

20.1 Conservation of atoms

In a chemical reaction every element keeps its count. This is the balance of a reaction equation. In the net: the addresses of the atoms persist; only the meetings between them are rewritten. Status: read; the balance itself is a measured law.[52]

20.2 Hess's law

Theorem B6 (Path independence). If the enthalpy H is a function of state, the enthalpy change of a reaction does not depend on the path:

$$\Delta H_{A\to C} = \Delta H_{A\to B} + \Delta H_{B\to C}\,.$$

Proof. ΔH is a difference of values of one function. ∎ Status: proven under input (H is a state function).[53]

In the net this is the same structure as N4: the response is a state function, not a property of the route.

20.3 Direction of a reaction

A reaction at constant temperature and pressure proceeds when the Gibbs energy falls, $\Delta G < 0$. Its equilibrium constant is

$$K = e^{-\Delta G^\circ/RT}\,.$$

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[52] A.-L. Lavoisier, *Traité élémentaire de chimie*, Paris, 1789.

[53] P. Atkins and J. de Paula, *Atkins' Physical Chemistry*, 11th ed., Oxford University Press, 2018, Chapters 2 and 6.

Both statements are input from thermodynamics.[54] In the net: $\Delta G < 0$ means that the products close better than the reactants. The entropy produced has an address (Physics T6).

20.4 Catalysis

A catalyst lowers the barrier between reactants and products and leaves the end states unchanged. In the net: with a catalyst an intermediate seam (Foundations T11) with less tension exists. The end states and ΔG stay the same. Status: read.

20.5 Redox

In a redox reaction electrons pass from one partner to the other. The total charge is conserved. In the net this is the conserved integer charge of Foundations T22 at the scale of the molecule. Status: read.

[54] P. Atkins and J. de Paula, *Atkins' Physical Chemistry*, 11th ed., Oxford University Press, 2018, Chapters 2 and 6.

21. Matter in Bulk

In short.

- Solid, liquid and gas differ in how far closures reach (read).
- A crystal is a word that closes in every direction (read).
- Each water molecule takes part in up to four hydrogen bonds; each is read as a closure of an open window (read).

21.1 Phases

Solid, liquid and gas differ in how far the closures between molecules reach. In a crystal the closures repeat in every direction: the analogue of a word that closes everywhere (Foundations T8). In a liquid they close locally and reopen. In a gas they are rare. Status: read.

21.2 Crystals

A crystal is a periodic arrangement. Periodicity is the condition of Foundations T8 at the scale of the lattice. The 230 space groups of crystallography are input.[55] Status: read.

21.3 Water

Water forms hydrogen bonds: open windows at the hydrogen atoms close with lone pairs on neighbouring oxygen atoms. Each molecule can take part in up to four such bonds. This gives the high boiling point and heat capacity of water. The values are input. Status: read.

21.4 What this part has reached

The atom enters with one input (the hydrogen spectrum) and the periodic table with a second (the Madelung order). From there the counting rules of chemistry follow by proof: shell capacity, period lengths, the parity of bonds, the ring count and the two mirror forms. They hold for every compound with an integer bond graph. The values of individual compounds remain measurements.

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[55] *International Tables for Crystallography*, Vol. A, 6th ed., International Union of Crystallography / Wiley, 2016.

Part IV — The Climate

22. The Climate

In short.

- A steady planet returns what it receives (energy balance, proven under input); the net reads this as a closure (read).
- The surface emits as a body at about 288 K (input; effective temperature 254.6 K computed).
- Sensitivity is a state function (read).

22.1 The planet as a closure

A planet in a steady state returns as much energy to space as it receives. In the net this is a closure: incoming and outgoing flux close the window of the planet. A difference between them is tension (N2). It passes on into the oceans, the ice and the air until the window closes again. Status: read.

22.2 Radiation

Every body radiates. The total flux per unit area of a black body is σT^4. The constant follows from Planck's law:

$$\sigma = \frac{2\pi^5 k^4}{15 h^3 c^2} = 5.6704 \times 10^{-8}\ \mathrm{W\ m^{-2} K^{-4}}.$$

Status: proven under input (Planck's law; constants h, c, k exact in SI). Recomputed (Appendix A.9).

The wavelength of maximum emission is $\lambda_{\max} = b/T$, with $b = 2.8978 \times 10^{-3}$ m K (Wien). For the Sun at 5,772 K the peak lies at 0.50 µm. For the Earth at 255 K it lies at 11.4 µm. The two spectra hardly overlap. Incoming light and outgoing heat pass through two different windows of the atmosphere.

22.3 The balance

The Earth receives a solar flux of about 1,361 W m⁻² at its mean distance.[56] It reflects about 30 % (the albedo).[57] It intercepts this flux on a disc and radiates from a sphere four times larger. The balance

$$\frac{S(1-A)}{4} = \sigma T_e^4$$

gives an effective radiating temperature

$$T_e = 254.6 \text{ K}\,.$$

The mean surface temperature is about 288 K. Trenberth et al. adopt a surface emission of 396 W m⁻², which corresponds to a black body at 289 K; the observed 1961–1990 mean is 287.0 K.[58] The difference of about 33 K is the greenhouse effect: the atmosphere absorbs outgoing infrared radiation and re-emits it, partly back to the surface. Status: proven under input (*S*, *A*, Planck's law).

22.4 The layers

The atmosphere is a stack of layers. Water vapour and carbon dioxide absorb in bands of the infrared; carbon dioxide has its main band near 15 μm.[59] Each layer receives from below and above and emits both ways. In the net the climate is a ladder of closures: surface, boundary layer, troposphere, stratosphere, space. A change in one layer passes on to the next as tension. Status: read.

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[56] G. Kopp and J.L. Lean, "A new, lower value of total solar irradiance", *Geophys. Res. Lett.* 38, 2011, L01706.

[57] K.E. Trenberth, J.T. Fasullo and J. Kiehl, "Earth's global energy budget", *Bull. Am. Meteorol. Soc.* 90(3), 2009, 311–323.

[58] K.E. Trenberth, J.T. Fasullo and J. Kiehl, "Earth's global energy budget", *Bull. Am. Meteorol. Soc.* 90(3), 2009, 311–323.

[59] R.T. Pierrehumbert, *Principles of Planetary Climate*, Cambridge University Press, 2010, Chapter 4.

22.5 Water

Water carries energy as latent heat. It evaporates at the surface and condenses higher up. The water cycle is a closed loop: what evaporates returns as precipitation. In the net it is a ring in the sense of Foundations T7: it closes and carries energy one layer up. Status: read.

22.6 Response as a state function

The climate response to a forcing is written $\Delta T = F/\lambda$, with λ the feedback parameter. In the net λ is not a constant. It is a state function of the climate (N4). The sensitivity measured in one state does not carry over unchanged to another. Status: read.

23. Climate Change

In short.

- Each doubling of CO_2 adds the same forcing (proven under H1–H4, B12).
- Without feedback a doubling warms by 1.05 K (proven under the black-body hypothesis; the IPCC Planck response gives 1.22 K).
- To 2100 Sun, orbit and planets are an order of magnitude below CO_2 (computed, 23.8).

23.1 The concentration

The pre-industrial concentration of CO_2 was about 278 ppm.[60] In 2024 the global mean was 423.9 ppm, a record. The rise from 2023 to 2024 was 3.5 ppm, the largest on record.[61] The ratio is

$$\frac{423.9}{278} = 1.525,$$

an increase of about 52 %.

23.2 The forcing

The radiative forcing of CO_2 grows with the logarithm of the concentration:

$$\Delta F = 5.35 \ln \frac{C}{C_0} \text{ W m}^{-2}.$$

The coefficient comes from radiative-transfer calculations.[62] For 423.9 ppm this gives $\Delta F = 2.26$ W m⁻² for CO_2 alone. A doubling gives $5.35 \ln 2 = 3.71$ W m⁻². The IPCC Sixth

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[60] IPCC, *Climate Change 2001: The Scientific Basis* (TAR), Working Group I, Chapter 6, Table 6.1 (pre-industrial 278 ppm) and Table 6.2 (5.35 ln(C/C_0)).

[61] World Meteorological Organization, *Greenhouse Gas Bulletin* No. 21, 15 October 2025.

[62] G. Myhre, E.J. Highwood, K.P. Shine and F. Stordal, "New estimates of radiative forcing due to well mixed greenhouse gases", *Geophys. Res. Lett.* 25(14), 1998, 2715–2718.

Assessment Report uses an effective forcing of 3.93 W m⁻² for a doubling.[63] The total human-caused effective forcing from 1750 to 2019 is 2.72 W m⁻². Greenhouse gases including their precursors contribute about 3.84 W m⁻² (well-mixed gases alone 3.32); aerosols contribute about −1.1 W m⁻² for 1750–2019.[64]

Reading. Each doubling of the concentration adds the same forcing. A doubling is one step on the ladder of meetings (Foundations T15). The logarithm is the count of steps on the ×2 ladder. Status: read. The logarithm itself follows from the shape of the absorption band (Chapter 25.4); the coefficient 5.35 is input.

23.3 The response without feedback

The radiation of the planet changes with temperature by

$$\frac{d\left(\sigma T^4\right)}{dT} = 4\sigma T_e^3 = 3.74 \text{ W m}^{-2}\text{K}^{-1}\,.$$

Under the hypothesis that the planet warms uniformly as a black body at T_e, a doubling of CO_2 without any feedback would warm it by $3.93/3.74 = 1.05$ K (Appendix A.10). Status: proven under that hypothesis. The IPCC uses a Planck response of 3.22 W m⁻² K⁻¹ (range 3.0–3.4), which includes the vertical temperature profile and gives 1.22 K.[65]

23.4 The response with feedbacks

Water vapour, clouds, ice and the lapse rate change with temperature. They change the net response. The IPCC assessed the equilibrium climate sensitivity — the warming after a doubling

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[63] P. Forster, T. Storelvmo et al., "The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity", in IPCC, *Climate Change 2021: The Physical Science Basis* (AR6 WGI), Chapter 7, Cambridge University Press, 2021.

[64] P. Forster, T. Storelvmo et al., "The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity", in IPCC, *Climate Change 2021: The Physical Science Basis* (AR6 WGI), Chapter 7, Cambridge University Press, 2021.

[65] P. Forster, T. Storelvmo et al., "The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity", in IPCC, *Climate Change 2021: The Physical Science Basis* (AR6 WGI), Chapter 7, Cambridge University Press, 2021.

once the system has settled — at a best estimate of 3 °C, likely between 2.5 and 4 °C, very likely between 2 and 5 °C.[66] [67] The implied net feedback parameter is $3.93/3 = 1.31$ W m^{-2} K^{-1}.

The transient response to cumulative emissions is about 0.45 °C per 1,000 Gt CO_2, likely 0.27–0.63 °C.[68]

23.5 Observed warming

The global surface temperature in 2011–2020 was 1.09 °C above 1850–1900.[69] The year 2024 was about 1.55 °C above that baseline, the warmest on record. The year 2025 was 1.44 ± 0.13 °C above it in the consolidated analysis of January 2026 and 1.43 ± 0.13 °C in the State of the Global Climate 2025 of March 2026; it ranks second or third warmest. The eleven years 2015–2025 are the eleven warmest on record.[70]

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[66] P. Forster, T. Storelvmo et al., "The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity", in IPCC, *Climate Change 2021: The Physical Science Basis* (AR6 WGI), Chapter 7, Cambridge University Press, 2021.

[67] J. Marotzke, "The newest IPCC report — a look behind the scenes", Max Planck Institute for Meteorology, 2021; S.C. Sherwood et al., "An assessment of Earth's climate sensitivity using multiple lines of evidence", *Rev. Geophys.* 58, 2020, e2019RG000678.

[68] IPCC, *Climate Change 2021: The Physical Science Basis*, Summary for Policymakers, statements A.1.2 and D.1.1.

[69] IPCC, *Climate Change 2021: The Physical Science Basis*, Summary for Policymakers, statements A.1.2 and D.1.1.

[70] World Meteorological Organization, *State of the Global Climate 2025*, March 2026; WMO consolidated temperature analysis, January 2026.

23.6 Reading in the net

Fact	Net reading	Status
Energy balance at the top of the atmosphere	Closure of the planet's window	Read
Energy imbalance	Tension (N2) that passes into ocean and ice	Read
Logarithmic forcing	Steps on the ×2 ladder; shape derived in 25.4	Read; known
Feedback parameter λ	State function (N4)	Read
Warming located per region	Loss has an address (Physics T6)	Read
Value of 5.35 W m^{-2}	—	Input (derivation open)
Values of the feedbacks	—	Open

23.7 What the net adds

The net adds no new number to climate science in this edition. It adds a reading. The planet is a closure. Under a forcing the window is open. The tension passes on through the layers until a new closure forms at a higher temperature. The rate of that passage depends on the state, because the response is a state function.

If λ is a state function, the sensitivity inferred from one period differs from the sensitivity in another period with a different state. Climate science already knows this as the pattern effect: estimates from the historical record come out lower than the equilibrium value.[71] Status: known; the state function is a reading (read). The direction and size of the difference are not derived in the net. Status: open.

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[71] P. Forster, T. Storelvmo et al., "The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity", in IPCC, *Climate Change 2021: The Physical Science Basis* (AR6 WGI), Chapter 7, Cambridge University Press, 2021.

23.8 External influences on the energy balance

Chapter 22 takes the solar flux as a fixed input. A forecast of the climate needs its variation as well. Three external influences enter the energy balance of the planet. They are treated separately here and then compared with the CO_2 forcing.

23.8.1 The Sun and its activity

The total solar irradiance varies with the magnetic cycle of the Sun, which lasts about 11 years on average. The change from minimum to maximum is about 0.1 % of 1361 W m⁻², about 1.4 W m⁻².[72] At the top of the atmosphere, averaged over the sphere and after reflection, a change ΔS gives the forcing

$$\Delta F = \frac{\Delta S (1 - A)}{4} .$$

With $A = 0.30$: $\Delta S = 1.0$ W m⁻² gives 0.175 W m⁻²; $\Delta S = 1.4$ W m⁻² gives 0.245 W m⁻². Over one cycle the forcing returns to its start. It adds no trend.

Between 1645 and 1715 few sunspots were seen (the Maunder Minimum).[73] A new grand minimum of that kind would reduce global warming by at most 0.3 °C by 2100, less than ten per cent of the 3.7–4.5 °C warming in the IPCC business-as-usual scenarios (Feulner and Rahmstorf 2010).[74] The size of solar change beyond one cycle is still under discussion.[75] Status: input (measured irradiance); computed (forcing).

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[72] Wikipedia, “Solar cycle” (TSI amplitude about 0.1 % around 1361.5 W m⁻²; average length about 11 years; Maunder Minimum 1645–1715); G. Kopp and J.L. Lean, *Geophys. Res. Lett.* 38, 2011, L01706.

[73] Wikipedia, “Solar cycle” (TSI amplitude about 0.1 % around 1361.5 W m⁻²; average length about 11 years; Maunder Minimum 1645–1715); G. Kopp and J.L. Lean, *Geophys. Res. Lett.* 38, 2011, L01706.

[74] G. Feulner and S. Rahmstorf, “On the effect of a new grand minimum of solar activity on the future climate on Earth”, *Geophys. Res. Lett.* 37, 2010, L05707; summary by the Potsdam Institute for Climate Impact Research, 10 March 2010.

[75] S.K. Solanki, N.A. Krivova and J.D. Haigh, “Solar irradiance variability and climate”, *Annu. Rev. Astron. Astrophys.* 51, 2013, 311–351, arXiv:1306.2770.

23.8.2 Orbit, axis and precession

The orbit and axis of the Earth change in three cycles (Milankovitch).[76]

Element	Present value	Trend	Main periods
Eccentricity e	0.0167	decreasing	about 100,000 and 405,000 years
Obliquity	23.44°	decreasing, minimum about AD 11,800	about 41,000 years, range 22.1°–24.5°
Precession (date of perihelion)	about 3 January	perihelion moves through the year	about 21,000 years at present

Deep-sea records show these periods in the ice ages ("pacemaker of the ice ages").[77]

The global annual mean insolation depends only on the eccentricity: $\bar{S} = S/\left(4\sqrt{1-e^2}\right)$. At $e = 0.0167$ this is 0.047 W m⁻² above the value for a circular orbit. Eccentricity changes by up to about 0.04 over half a cycle of 100,000 years. At present the global mean changes by about 2×10^{-4} W m⁻² per century, below 0.001 W m⁻². Obliquity and precession redistribute the flux over latitudes and seasons; they leave the global annual mean unchanged. Their effect on the climate runs through the response of ice sheets in the northern summer.

Without human CO_2 the next glacial inception would most likely not occur within 50,000 years (Berger and Loutre 2002; Ganopolski, Winkelmann and Schellnhuber 2016). Emissions of

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[76] M. Milanković, *Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem*, Belgrade, 1941; J. Laskar et al., "A long-term numerical solution for the insolation quantities of the Earth", *Astron. Astrophys.* 428, 2004, 261–285; values as summarised in Wikipedia, "Milankovitch cycles".

[77] J.D. Hays, J. Imbrie and N.J. Shackleton, "Variations in the Earth's orbit: pacemaker of the ice ages", *Science* 194, 1976, 1121–1132.

1,000–1,500 Gt of carbon would postpone it by at least 100,000 years.[78] Status: input (orbital elements); computed (global mean); known (glacial inception).

23.8.3 The planets

The planets enter the climate of the Earth in two ways.

Through the orbit of the Earth. The orbital part of the Milankovitch cycles comes from the perturbations by the planets; the axial part also comes from the torque of Sun and Moon on the equatorial bulge. The 405,000-year eccentricity cycle is the beat $g_2 - g_5$ of two secular frequencies, dominated by Venus and Jupiter. Recent integrations find that this beat can weaken or vanish through a secular resonance, in about 40 % of the computed solutions, hundreds of millions of years in the past.[79] The 100,000-year bands and the 41,000-year obliquity cycle depend on Mars; with a more massive Mars they would lengthen.[80] This influence is large over tens of thousands of years. Over one century it falls under the same bound as in 23.8.2: below 0.001 W m^{-2} in the global mean. Status: known.

Directly. The tide that a planet raises on the Earth scales with M/d^3. Against the tide of the Moon:

Body (closest approach)	Tide relative to the Moon
Sun	0.48
Venus	6.9×10^{-5}
Jupiter	7.1×10^{-6}
Mars	3.0×10^{-6}

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[78] A. Berger and M.F. Loutre, “An exceptionally long interglacial ahead?”, *Science* 297, 2002, 1287–1288; A. Ganopolski, R. Winkelmann and H.J. Schellnhuber, “Critical insolation–CO_2 relation for diagnosing past and future glacial inception”, *Nature* 529, 2016, 200–203.

[79] R.E. Zeebe and M.L. Lantink, “A secular solar system resonance that disrupts the dominant cycle in Earth’s orbital eccentricity (g2–g5): Implications for astrochronology”, *Astron. J.*, 2024, doi:10.3847/1538-3881/ad32cf, arXiv:2403.09332.

[80] S.R. Kane, P. Vervoort and J. Horner, “The dependence of Earth Milankovitch cycles on Martian mass”, *Publ. Astron. Soc. Pac.* 137, 2025, 124402, arXiv:2512.02108.

Body (closest approach)	Tide relative to the Moon
Saturn	2.6×10^{-7}

Moon at its mean distance of 384,400 km; closest approaches 0.983 AU (Sun), 38 million km (Venus), 54.6 million km (Mars), 3.95 AU (Jupiter), 8.0 AU (Saturn). Status: computed (Appendix A.20).

The direct tides of the planets on the Earth are negligible.

Through the Sun. One hypothesis holds that the solar cycle is phase-locked to the 11.07-year alignment period of the tides of Venus, Earth and Jupiter (Stefani, Giesecke and Weier 2019).[81] Cameron and Schüssler (2013) found no evidence for a planetary influence on solar activity.[82] Status: open (contested).

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[81] F. Stefani, A. Giesecke and T. Weier, "A model of a tidally synchronized solar dynamo", *Solar Phys.* 294, 2019, 60, arXiv:1803.08692.

[82] R.H. Cameron and M. Schüssler, "No evidence for planetary influence on solar activity", *Astron. Astrophys.* 557, 2013, A83, arXiv:1307.5988.

23.8.4 Combined, against CO_2

Influence	Forcing	Time scale	Trend to 2100
CO_2 since 1750	2.26 W m^{-2} (23.2)	decades	rising with emissions
CO_2 doubling	3.93 W m^{-2} (23.2)	decades	—
Solar cycle	±0.12 W m^{-2} about the mean (0.245 from minimum to maximum)	11 years	none
Solar grand minimum	at most 0.3 °C of cooling by 2100	decades to a century	possible, not predictable
Orbit (global mean)	below 0.001 W m^{-2} per century	10^4–10^5 years	negligible
Orbit (seasonal, by latitude)	tens of W m^{-2} at 65° N in summer over a precession cycle	10^4–10^5 years	negligible per century
Planets, direct tide	$\leq 7\times10^{-5}$ of the lunar tide	—	negligible
Planets via the Sun	not established	11 years	open

Up to 2100 the external influences are an order of magnitude smaller than the CO_2 forcing. Over tens of thousands of years the orbital terms are the largest, and the insolation threshold for the next glacial inception depends on the CO_2 level.

23.8.5 Reading in the net

Fact	Net reading	Status
Solar cycle	An inner winding of the solar knot; its period is a ratio of counts (N7)	Read
Milankovitch cycles	Beats between the windings of the planets (orbit) and of the Sun–Moon torque on the Earth (axis); the 405,000-year cycle is the beat of the Venus and Jupiter windings	Read; the frequencies are known, not derived
Climate response to orbital forcing	A state function (N4): the same insolation gives a glacial inception or not, depending on CO_2	Read; known (Ganopolski et al.)
Planetary tide on the Sun	—	Open

The net derives none of these periods. It reads them as ratios of windings, which by N7 is what a period is. A forecast from the net would need the windings of the planets and the Sun as counts. That is open.

24. The Ledger

In short.

- From the first distinction to the comma the ground holds by proof, with one GAP in the trit rule; knot and coupling hold under named hypotheses.
- Maxwell's structure, Dirac motion in 1+1, the attraction of like sources and the counting rules of chemistry hold under named hypotheses or input.
- What remains is listed with its test (Ch. 28).

24.1 Count of statuses

Domain	proven	proven under named hypotheses or input	read	known	open / GAP
Ground (Ch. 1–8)	T1–T4, T7–T13, T16–T18	T14 (orbits), T15, T19–T24	Mark, eigenform, imaginary unit, sign of charge	T12, T13, T16–T22	IX.1–IX.5; trit rule at the ends (GAP)
Physics (Ch. 9–15)	T1–T5 (identities)	Units; a_0 reading; P1 as registered prediction	C1–C6, I1–I4; proton as closure of three, triality, released tension (15.5–15.7)	T6, a_0 coincidence, P3	O3–O8; P4 (GAP)
Chemistry (Ch. 16–21)	B3, B4, B7	B1, B2, B5, B6, B8	Bond as meeting, closed shells, phases	Hückel, Madelung, alkane counts	O_2 ground state; cluster bonding; single-compound values

Domain	proven	proven under named hypotheses or input	read	known	open / GAP
Climate (Ch. 22–23)	—	Radiation balance, no-feedback response; external influences computed (23.8)	Closure, tension, ladder, state function; orbital cycles as beats	Pattern effect; logarithmic forcing; Milankovitch; glacial inception	Forcing coefficient, feedback values; windings of Sun and planets as counts
Reduced links (Ch. 25)	B13 (exhaustive)	B9, B10 (1+1), B11, B12, B14, B15, B16	Mass as reversal; metallic bonding; gravity as scalar register; H-R	B9–B12, B14–B16 (in the literature)	Constants of ★; 3+1 Dirac; H-Q1′; vector and tensor gravity; R1–R29 (Ch. 28)

24.2 The chain that holds by proof

From the first distinction to the comma the chain holds by proof (Chapters 1–6), with one GAP in the trit rule at the ends of the strand. From the knot to the coupling it holds under named hypotheses (Chapters 7–8). The mass shell, spin, charge and entropy production hold under named inputs (Chapters 9–12). The counting rules of chemistry hold by proof for every compound (Chapters 18–19). The radiation balance of the planet holds under the inputs of Planck's law, the solar flux S and the albedo A (Chapter 22). The logarithm of CO_2 forcing holds under the spectroscopic inputs and hypotheses of Theorem B12 (Chapter 25.4).

24.3 The links that are read

Maxwell’s field, gravity, the closed shell, the bond, the phases of matter and the climate feedbacks are read in the language of the net. These readings are declared. They can fail.

24.4 The links that are open

Code	Open link
IX.1 / O1	Lever of the free path = coupling of the net (closed under H-R, 25.7)
O3	The mass spectrum, including m_p/m_e, and the electric charge
O4	One state variable χ
O5	Maxwell's equations from N1–N5
O6	Dirac's equation from N1–N5
O7	The fine-structure constant
O8	The Hubble constant or the turn, independently
—	General relativity
—	Nuclear binding and decay
—	The Madelung order and its exceptions
—	The ground state of O_2 and other orbital effects
—	Property values of individual compounds
—	Metallic and cluster bonding (intermetallics, borides)
—	The CO_2 forcing coefficient and the climate feedbacks

Each open link is a task. Each closed link can be checked with the calculations of Appendix A.

Part V — Closing Open Links

25. Links Reduced Under Named Hypotheses

In short.

- Under named hypotheses or input, Maxwell's structure, Dirac in 1+1, ring closure and logarithmic forcing follow (B9–B12).
- Under H-G1 like sources attract (B14); under H-R lever equals coupling (B15); under N6 and the input H-S light bends by refraction (B16).
- 10^{-37} reduces to α and one length ratio.

This chapter takes open links from Chapter 24 and reduces them as far as a proof reaches. Each theorem names its hypotheses. Each result was checked by an independent judge under the Respondent–Judge protocol (Chapter 27). Where the result is already in the literature, the status says so.

25.1 The field from Maxwell's quaternion equations (O5)

The source. In Article 619 of the *Treatise* (1873) Maxwell writes his electromagnetic equations in quaternion form.[83] The vector parts are written V, the scalar parts S, and $\nabla = \mathbf{i}\,\partial_x + \mathbf{j}\,\partial_y + \mathbf{k}\,\partial_z$ acts with Hamilton's one product.

	Maxwell's equation	Name
(A)	$\mathfrak{B} = V\,\nabla\mathfrak{A}$	magnetic induction
(B)	$\mathfrak{E} = V\mathfrak{G}\mathfrak{B} - \dot{\mathfrak{A}} - \nabla\Psi$	electromotive intensity
(C)	$\mathfrak{F} = V\mathfrak{C}\mathfrak{B} - e\,\nabla\Psi - m\,\nabla\Omega$	mechanical force
(D)	$\mathfrak{B} = \mathfrak{H} + 4\pi\mathfrak{J}$	magnetization
(E)	$4\pi\mathfrak{C} = V\,\nabla\mathfrak{H}$	electric currents

[83] J.C. Maxwell, *A Treatise on Electricity and Magnetism*, Clarendon Press, Oxford, 1873, Vol. II, Arts. 617–619 and 784; list of the quaternion equations checked against a transcription of the first edition (fabri.sagredo.eu) and against the lecture notes of F.W. Hehl on the changing form of Maxwell's equations, University of Cologne (thp.uni-koeln.de). Article 618 contains no field equations; it introduces the notation in a table of vector symbols and notes that K and μ, and probably C, are self-conjugate.

	Maxwell's equation	Name
(F)	$\mathfrak{D} = \frac{1}{4\pi} K \mathfrak{E}$	electric displacement
(G)	$\mathfrak{K} = C \mathfrak{E}$	conduction (Ohm)
(H)	$\mathfrak{C} = \mathfrak{K} + \dot{\mathfrak{D}}$	total current
(L)	$\mathfrak{B} = \mu \mathfrak{H}$	induced magnetization
(J)	$e = S \nabla \mathfrak{D}$ (and, unlettered, $m = S \nabla \mathfrak{I}$)	volume densities
—	$\mathfrak{H} = - \nabla \Omega$	magnetic potential (no letter)

Maxwell's letters (A)–(L) are those of Articles 591–614; in Article 619 only (A)–(E) are printed with letters.

In Article 617 Maxwell fixes the scalar part of the potential: $S \nabla \mathfrak{A} = 0$.

Setting on the net. Two hypotheses carry the field onto the net.

- **H-Q1.** Every place carries a quaternion: a scalar part and a vector part. For the potential the vector part is Maxwell's $\mathfrak{A}$; its scalar register is $S \nabla \mathfrak{A}$ (Art. 617). Maxwell's scalar potential Ψ enters through $\nabla \Psi$ in (B).
- **H-Q2.** ∇ is built from one and the same step difference D in each of the three directions, and the steps commute: $D_x D_y = D_y D_x$. This holds on a flat net, where a step in x followed by a step in y reaches the same place as the reverse order.

Theorem B9 (Maxwell's structure from closure of ∇). Under H-Q1 and H-Q2:

1. $\nabla \nabla = - \left(D_x^2 + D_y^2 + D_z^2 \right)$. Applied twice, ∇ is a pure scalar operator.
2. $S \nabla V \nabla X = 0$ for every vector field X. With (A): $S \nabla \mathfrak{B} = 0$. With (E): $S \nabla \mathfrak{C} = 0$, so the total current (H) always closes.
3. $V \nabla \nabla \Psi = 0$ for every scalar Ψ. With (B) at rest ($\mathfrak{G} = 0$): $V \nabla \mathfrak{E} = - \dot{\mathfrak{B}}$ (Faraday's law).

4. Under $\mathfrak{A} \to \mathfrak{A} + \nabla\lambda$, $\Psi \to \Psi - \dot{\lambda}$, the fields $\mathfrak{B}$ and $\mathfrak{E}$ do not change. The scalar register $S\,\nabla\mathfrak{A}$ changes by $-\left(D_x^2 + D_y^2 + D_z^2\right)\lambda$. The scalar register therefore carries the gauge freedom; Maxwell's condition $S\,\nabla\mathfrak{A} = 0$ (Art. 617) fixes it up to λ with $\sum D^2\lambda = 0$ (on a periodic net the constants and, for some sizes, a few more).
5. With (F), (G) and (L) as input, no conduction current, $\Psi = 0$ and $S\,\nabla\mathfrak{A} = 0$, with K and μ uniform and the second difference symmetric ($\sum D^2$ read as $\sum D^b D^f$, as in the staggered arrangement of Yee 1966):

$$K\mu\,\ddot{\mathfrak{A}} = \left(D_x^2 + D_y^2 + D_z^2\right)\mathfrak{A},$$

a wave with speed $1/\sqrt{K\mu}$ in the limit of small steps (Art. 784).

Proof. (1) Expand $\left(\mathbf{i}D_x + \mathbf{j}D_y + \mathbf{k}D_z\right)^2$. The squares give $\mathbf{i}^2 D_x^2 = -D_x^2$ and likewise. The cross terms come in pairs, such as $\mathbf{ij}D_xD_y + \mathbf{ji}D_yD_x = \mathbf{k}\left(D_xD_y - D_yD_x\right)$, which vanishes by H-Q2. (2) $\nabla\nabla X$ is a scalar operator applied to a vector, hence a vector; its scalar part $S\,\nabla\nabla X = S\,\nabla(S\,\nabla X + V\,\nabla X)$ is zero. The term $S\,\nabla(S\,\nabla X)$ is a scalar operator times ∇ applied to a scalar and has no scalar part. Hence $S\,\nabla V\,\nabla X = 0$. (3) $\nabla\nabla\Psi$ is a scalar, so its vector part is zero. Apply $V\,\nabla$ to (B): $V\,\nabla\mathfrak{E} = -V\,\nabla\dot{\mathfrak{A}} - V\,\nabla\nabla\Psi = -\dot{\mathfrak{B}}$, since time and step differences commute. (4) $V\,\nabla\nabla\lambda = 0$ leaves $\mathfrak{B}$ fixed; $-\nabla\dot{\lambda} + \nabla\dot{\lambda} = 0$ leaves $\mathfrak{E}$ fixed; $S\,\nabla\nabla\lambda = -\sum D^2\lambda$. (5) From (E), (H), (F), (L): $K\dot{\mathfrak{E}} = \frac{1}{\mu}V\,\nabla V\,\nabla\mathfrak{A}$. With $S\,\nabla\mathfrak{A} = 0$, $V\,\nabla\mathfrak{A} = \nabla\mathfrak{A}$ and $V\,\nabla V\,\nabla\mathfrak{A} = \nabla\nabla\mathfrak{A} = -\sum D^2\mathfrak{A}$. With $\mathfrak{E} = -\dot{\mathfrak{A}}$ the stated equation follows. ∎

Counterexample to a weaker hypothesis. If ∇ is applied the first time with forward differences and the second time with backward differences, the cross terms $\mathbf{k}\left(D_x^b D_y^f - D_y^b D_x^f\right)$ do not vanish and (1) fails. Identity (1) needs the same step in both factors. A staggered (Yee) arrangement keeps (2)–(4), each with one step inside the identity, and pairs forward with backward only in (5), where $\sum D^b D^f$ gives a real dispersion. With a forward difference applied twice the frequency becomes complex and some modes grow. Checked (Appendix A.11).

Status: proven under H-Q1, H-Q2 and, for (5), the constitutive inputs (F), (G), (L). An independent judge confirmed (1)–(4) exactly on four further lattices, including non-cubic ones. Checked exactly in integer arithmetic on a periodic $4 \times 5 \times 3$ net: every residual of (1)–(4) is exactly zero (Appendix A.11). Known: these are the quaternion forms of div curl = 0 and curl grad = 0; Maxwell used them in Articles 617–619. The equivalent cell-complex form with $F = dA$ and $dd = 0$ goes back to Yee (1966) and Teixeira and Chew (1999).[84]

Reading in the net. Two applications of ∇ close. The vector parts cancel in pairs, $\mathbf{ij} + \mathbf{ji} = 0$ together with $D_x D_y = D_y D_x$: meetings. What remains is scalar: a standing (Foundations T7). The scalar register is the register of the gauge: Maxwell sets it to zero in Article 617, which in the net reads as the potential closing at its own scale. Status: read.

What remains open.

- The coefficients K, C and μ, and with them the speed $1/\sqrt{K\mu}$, are input. In the net they are state functions (N4); their values are not derived. This hangs on the bridge from counts to constants (O1).
- The motional term $V\mathfrak{G}\mathfrak{B}$ in (B) and the force law (C) are input.
- H-Q2 is flatness. If steps do not commute, as with a position-dependent step on a curved net (a twisted but flat identification still commutes), $\nabla\nabla$ acquires a vector part and (2)–(3) fail; the vector part is $\sum \mathbf{e}_k \left[D_i, D_j \right]$. Whether gravity is that failure is open.
- Why every place carries a quaternion (H-Q1) is not yet a consequence of N1–N5. The Ninth Edition reads the local state as a quaternion rotor (C2).

O5 is therefore reduced, not closed: the structure of Maxwell's quaternion equations follows from the closure of ∇ on a flat net; the constants, the force law and the two hypotheses remain.

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[84] K.S. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media", *IEEE Trans. Antennas Propag.* 14(3), 1966, 302–307; K.G. Wilson, "Confinement of quarks", *Phys. Rev. D* 10, 1974, 2445–2459; F.L. Teixeira and W.C. Chew, "Lattice electromagnetic theory from a topological viewpoint", *J. Math. Phys.* 40, 1999, 169–187.

25.2 Motion (O6)

Setting. A passage has a direction: forward $(+1)$ or back (-1). At each step the strand moves one place in its direction. Between steps it keeps its direction with amplitude $\cos\theta$ or reverses with amplitude $-i\sin\theta$ (hypothesis H-D1: amplitudes are complex numbers; the unit i is the re-entry of Chapter 1.2). One step in momentum space is

$$U(k) = \begin{pmatrix} e^{ik} & 0 \\ 0 & e^{-ik} \end{pmatrix} \begin{pmatrix} \cos\theta & -i\sin\theta \\ -i\sin\theta & \cos\theta \end{pmatrix}.$$

Theorem B10 (Mass as reversal). The eigenvalues of $U(k)$ are $e^{\pm i\omega}$ with

$$\cos\omega = \cos\theta \cos k$$

exactly. For $k = p\varepsilon$ and $\theta = m\varepsilon$ with $\varepsilon \to 0$:

$$\left(\frac{\omega}{\varepsilon}\right)^2 = p^2 + m^2 + O(\varepsilon^2),$$

and $(U - 1)/(-i\varepsilon) \to -p\,\sigma_z + m\,\sigma_x$, the Dirac Hamiltonian in one space dimension.

Proof. U is unitary, $\det U = 1$ and $\mathrm{tr}\,U = 2\cos\theta\cos k$. The eigenvalues of a unitary 2×2 matrix with unit determinant are $e^{\pm i\omega}$, with $2\cos\omega$ equal to the trace. Expanding $\cos\omega = \cos\theta\cos k$ to second order gives $\omega^2 = \theta^2 + k^2 + O(4)$. The first-order term of U gives the generator. ∎

Status: proven in one space dimension under H-D1. Checked: largest deviation of $\cos\omega$ from $\cos\theta\cos k$ is 3.9×10^{-16} over 656 points; ω/ε converges to $\sqrt{p^2 + m^2}$ (Appendix A.12).

Known: Feynman's checkerboard and its analysis by Jacobson and Schulman; the discrete quantum walk of Meyer and of Strauch, where $\cos\omega = \cos\theta\cos k$ appears; the three-dimensional form as a unitary cellular automaton by Bialynicki-Birula.[85]

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[85] R.P. Feynman and A.R. Hibbs, *Quantum Mechanics and Path Integrals*, McGraw-Hill, 1965, Problem 2-6; T. Jacobson and L.S. Schulman, "Quantum stochastics: the passage from a relativistic to a non-relativistic path integral", *J. Phys. A* 17, 1984, 375–383; I. Bialynicki-Birula, "Weyl, Dirac, and Maxwell equations on a lattice as unitary cellular automata", *Phys. Rev. D* 49, 1994, 6920–6927; D.A. Meyer, "From quantum cellular automata to quantum lattice gases", *J. Stat. Phys.* 85, 1996, 551–574; F.W. Strauch, "Relativistic quantum walks", *Phys. Rev. A* 73, 2006, 054302.

Reading. Mass is the amplitude of reversal; this reading goes back to Feynman's checkerboard. A reversal pairs a forward and a backward passage: a meeting. A strand that never reverses ($\theta = 0$) moves at the limit speed: $\omega = |k|$. This is light. The relation $E^2 = p^2 + m^2$ of Chapter 9 now follows from the strand itself in one dimension, with H-D1, the form of the step and $\theta = m\varepsilon$ as hypotheses in place of Dirac's equation. Status of the reading: read; known.

What remains open. The three-dimensional case with four components is not proven in this book. Why the amplitudes are complex (H-D1) rests on the reading of re-entry, which is read.

25.3 Bonding in rings and metals

Setting. N places form a ring. Neighbours couple with equal strength t (input: the tight-binding form of quantum chemistry).[86] The state must close on itself: $\psi_{n+N} = \psi_n$.

Theorem B11 (Ring closure). The allowed energies are

$$E_m = -2t\cos\frac{2\pi m}{N}, \qquad m = 0, 1, \ldots, N-1\,.$$

Proof. Closure forces $\psi_n = e^{ikn}$ with $e^{ikN} = 1$, so $k = 2\pi m/N$. Inserting in the coupling gives $E = -t\left(e^{ik} + e^{-ik}\right)$. ∎ Status: proven under the input. Checked against direct diagonalisation for $N = 3$ to 14 (Appendix A.13), and by the independent judge for $N = 3$ to 30.

Corollary B11.1 (The 4n+2 rule). The lowest level is single. Every higher level except the top for even N is a pair (m and $-m$). With two electrons per state, the filled levels close at

$$2,\ 6,\ 10,\ 14,\ \ldots = 4n + 2\,.$$

Benzene has 6 π electrons and closes. Cyclobutadiene has 4 and does not. This is Hückel's rule. Status: proven under the input; known (Hückel 1931).

Corollary B11.2 (Metallic bonding). As $N \to \infty$ the levels fill the band $[-2t, 2t]$ with no gap. The largest spacing at $N = 1000$ is 0.0126 t. A partly filled band closes over the whole ring rather than in local pairs. This is the net reading of metallic bonding: closure that is delocalised over the ring. Status: proven (band, under the tight-binding input); metallic bonding read. It gives

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[86] E. Hückel, "Quantentheoretische Beiträge zum Benzolproblem", *Z. Phys.* 70, 1931, 204–286; F. Bloch, "Über die Quantenmechanik der Elektronen in Kristallgittern", *Z. Phys.* 52, 1929, 555–600.

a reading for the intermetallics of Chapter 19.6, not a derivation of their bonding. Cluster bonding of borides remains open.

25.4 The logarithm of CO_2 forcing

Setting. Away from the band centre ν_c at 667 cm^{-1}, the absorption cross-section of CO_2 falls exponentially: $\sigma(\nu) = \sigma_c\, e^{-|\nu - \nu_c|/w}$ (H1, input from spectroscopy). Emission to space comes from the surface at T_s where the band is thin and from one upper layer at T_t where it is thick (H2). The change from thin to thick is sharp (H3). The Planck radiance is taken constant across the band at its value at ν_c, and overlap with water vapour is neglected (H4).

Theorem B12 (Logarithmic forcing). Each factor e in concentration widens the thick part of the band by $2w$, one w on each wing. The forcing per unit of $\ln C$ is

$$\alpha = 2\pi w \left[B(\nu_c, T_s) - B(\nu_c, T_t) \right],$$

with B the Planck radiance and T_s, T_t the surface and upper-layer temperatures.

Proof. The edge of the thick region lies where $C\sigma(\nu)$ reaches a fixed value; hence $|\nu - \nu_c| = w \ln C + \text{const}$. The width grows by $2w$ per unit of $\ln C$. Across that width the emission changes from $B(T_s)$ to $B(T_t)$; integration over the hemisphere gives π. ∎ Status: proven under H1–H4; known (Romps, Seeley and Edman 2022; Wordsworth, Seeley and Shine 2024, whose equation 7 is the same formula; with $w = 0.40$ THz = 13.34 cm^{-1} it gives 7.37–7.39 W m^{-2}).[87]

w (cm^{-1})	T_s (K)	T_t (K)	α (W m^{-2})	Per doubling (W m^{-2})
12.5	288	217	6.91	4.79
13.3	288	217	7.35	5.10

[87] D.M. Romps, J.T. Seeley and J.P. Edman, "Why the forcing from carbon dioxide scales as the logarithm of its concentration", *J. Climate* 35(13), 2022, 4027–4047, doi:10.1175/JCLI-D-21-0275.1; R. Wordsworth, J.T. Seeley and K.P. Shine, "Fermi resonance and the quantum mechanical basis of global warming", *Planet. Sci. J.* 5(3), 2024, 67, doi:10.3847/PSJ/ad226d.

w (cm^{-1})	T_s (K)	T_t (K)	α (W m^{-2})	Per doubling (W m^{-2})
12.5	289	205	7.81	5.41

The detailed radiative-transfer value is 5.35 W m^{-2} per unit of $\ln C$. The simple formula exceeds it by 29–46 %; the authors attribute this to its idealisations. This is not a proven bound.

Reading. The derivation uses spectroscopic inputs only, not a premise of the net. The logarithm is therefore proven under input and already known. That a doubling is one step on the ×2 ladder, and every step adds the same width, is the net's reading. Status: read. The coefficient 5.35 stays input; B12 gives 6.9–7.8 W m^{-2} under its idealisations.

25.5 Can the windows carry the quaternion product? (H-Q1)

Theorem B9 uses hypothesis H-Q1: the three step directions of the net carry Hamilton's units $\mathbf{i}, \mathbf{j}, \mathbf{k}$ with $\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = \mathbf{ijk} = -1$. This section tests whether H-Q1 follows from window closure alone.

Setting. A window is a triple (x, y, z) of trits. It is closed when $x + y + z \equiv 0 \pmod 3$ (Chapter 3). There are 9 closed windows. Two windows combine place by place mod 3, without carry, with representatives −1, 0, 1. The six closed windows that contain each trit once are called heterogeneous; the other three are $(0, 0, 0)$, $(1, 1, 1)$ and $(-1, -1, -1)$.

Theorem B13 (Axes yes, product no).

1. The 9 closed windows form a group under place-by-place addition. It is $\mathbb{Z}_3 \times \mathbb{Z}_3$: abelian, every element besides $(0, 0, 0)$ of order 3.
2. No homomorphism from this group into the multiplicative group of non-zero quaternions sends any window to -1 or to one of $\pm\mathbf{i}, \pm\mathbf{j}, \pm\mathbf{k}$. The quaternion group Q_8 cannot be carried by window addition.
3. The six heterogeneous windows map one-to-one onto $\pm\mathbf{i}, \pm\mathbf{j}, \pm\mathbf{k}$: the axis is the place of the 0, the sign is the trit that follows it in cyclic order. Under this map, negating a window negates the unit, and a cyclic shift of places permutes the axes cyclically. The map is a labelling, not a homomorphism (by point 2), and one convention among several; taking the sign from the trit before the 0 works equally well.

4. Of the 24 ordered pairs of units on different axes, 12 add (as windows) to a unit on the third axis and 12 do not. The 12 that close are exactly the pairs of equal sign: $u + v = -\sigma\,\hat{w}$, with σ the common sign and $\hat{w}$ the positive unit of the third axis. Pairs of opposite sign give $(1, 1, 1)$ or $(-1, -1, -1)$. The sum never depends on order. (As quaternions, the sum of two units on different axes has norm $\sqrt{2}$ and is never a unit.)

Proof. (1) The closure condition is linear mod 3, so the closed windows are the kernel of $(x, y, z) \mapsto x + y + z$ on $\mathbb{Z}_3^3$, a subgroup of order 9 in which $3w = 0$ for all w. (2) Every window w satisfies $3w = 0$, so its image h satisfies $h^3 = 1$. But -1 has order 2 and each of $\pm\mathbf{i}, \pm\mathbf{j}, \pm\mathbf{k}$ has order 4; neither divides 3. (3) and (4): exhaustive check of all cases (Appendix A.15). The sum of the units on $\mathbf{i}$ and $\mathbf{j}$ is $-\mathbf{k}$; Hamilton's product is $\mathbf{ij} = \mathbf{k}$ and $\mathbf{ji} = -\mathbf{k}$. Addition is commutative and cannot separate the two. ∎

Status: proven (exhaustive). Known: that $\mathbb{Z}_3^2$ is abelian and Q_8 is not is standard group theory; the map of point 3 is new as a note.

Reading. Closure admits a labelling of the six heterogeneous windows by the three axes and two signs of Hamilton's units that respects negation and cyclic symmetry. It does not give the product. The product needs one more distinction: which of two meeting windows came first. The net has a natural place for this in N3 (memory of order). Hypothesis H-Q1 is therefore reduced to:

- **H-Q1′.** A meeting of two heterogeneous windows on different axes records its order as a sign $\varepsilon = +1$ for cyclic order and $\varepsilon = -1$ against it.

Under H-Q1′ the rule $u \cdot v = \varepsilon(u, v)\,\sigma(u)\,\sigma(v)\,\hat{w}$, with σ the sign of a unit and $\hat{w}$ the positive unit of the third axis, together with $u \cdot u = -1$ and $u \cdot (-u) = +1$, is Hamilton's product by construction. For example $(-\mathbf{i}) \cdot \mathbf{j} = -\mathbf{k}$. The window sum cannot supply this sign: $(+\mathbf{i}) + (+\mathbf{j})$ gives $-\mathbf{k}$, while $\mathbf{ij} = +\mathbf{k}$. That step is a definition, not a derivation. Status of H-Q1: open, reduced to H-Q1′. The open question is whether N3 supplies ε.

25.6 Why like sources attract: Maxwell's gravitational difficulty (O1)

The difficulty. In 1864 Maxwell asked whether gravitation could be a state of a medium, as he had shown for electricity and magnetism.[88] In his treatment the energy of the medium is a constant C minus a term in the square of the resultant force R (his equation 47). Like masses attract, so the energy must fall where the field rises. For the energy to stay positive the medium must possess, "when undisturbed, an enormous intrinsic energy". He concluded: "As I am unable to understand in what way a medium can possess such properties, I cannot go any further in this direction in searching for the cause of gravitation." The negative field energy density $-\left|\nabla\Phi\right|^2/8\pi G$ of Newtonian gravity is the modern form of the same point.[89]

Setting. Take the static density deviation δ of the net (the relative visit density of the strand) on a cubic net or in space, linearised at the reference state of Foundations T23. Its energy is

$$E[\delta] = \sum \left[\frac{\bar{g}}{2}\delta^2 + \frac{\kappa}{2}\left|\nabla\delta\right|^2 - s\,\delta \right],$$

with stiffness $\bar{g} \geq 0$, gradient stiffness $\kappa > 0$ and sources s (hypothesis H-G1: the sources of gravity couple linearly to δ). Two point sources q_1, q_2 sit at distance r.

Theorem B14 (Sign of the static coupling).

1. For $\bar{g} > 0$ the energy has one minimum, $\delta = G * s$ with $G = \left(\bar{g} - \kappa\nabla^2\right)^{-1}$. Every value of G is positive.
2. At the minimum $E_{\min} = -W$, with $W = \sum \left[\frac{\bar{g}}{2}\delta^2 + \frac{\kappa}{2}\left|\nabla\delta\right|^2 \right] \geq 0$ the field energy.
3. The interaction energy is $U(r) = -q_1 q_2\, G(r)$. Sources of equal sign attract; sources of opposite sign repel.

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[88] J.C. Maxwell, "A Dynamical Theory of the Electromagnetic Field", *Phil. Trans. R. Soc. Lond.* 155, 1865, 459–512 (read 8 December 1864), §82 "Note on the Attraction of Gravitation", pp. 492–493, equation (47). Wording checked against a facsimile scan and against mathpages.com, "Maxwell's note on gravitation".

[89] I. Bengtsson and T. Eklund, "Energy in Newtonian gravity", *Found. Phys.* 53, 15 (2023; online 2022), doi:10.1007/s10701-022-00660-z, arXiv:2112.06503, equations (1), (7) and (22), with Maxwell's remark quoted.

4. In space, $G(r) = e^{-r/\ell}/(4\pi\kappa r)$ with range $\ell = \sqrt{\kappa/\bar{g}}$. The $1/r$ law of Newton requires $\bar{g} \to 0$ at the reference state. For $\bar{g} < 0$ there is no minimum.
5. Under T23 (input) the local stiffness is $g_{\text{eff}} = \bar{g}\big(1 + \gamma\delta\big)$. In the local approximation (slowly varying δ) the range $\ell/\sqrt{1+\gamma\delta}$ diverges where $\gamma\delta = -1$.

Proof. (1) On the net, $\bar{g} - \kappa\nabla^2$ is a symmetric matrix with positive diagonal $\bar{g} + 6\kappa$, off-diagonal entries $-\kappa$ and diagonal excess $\bar{g} > 0$. (On a periodic or infinite net the diagonal is $\bar{g} + 6\kappa$; in general $\bar{g} + \kappa$ times the number of neighbours.) It is a non-singular M-matrix; its inverse is entrywise non-negative, and positive because the net is connected.[90] (2) At the minimum $\big(\bar{g} - \kappa\nabla^2\big)\delta = s$. Multiplying by δ and summing (by parts) gives $2W = \sum s\delta$. Then $E = W - \sum s\delta = -W$. (3) $E_{\min} = -\dfrac{1}{2}\sum_{x,y} s(x)G\big(x-y\big)s\big(y\big)$. The cross term of two point sources is $-q_1 q_2 G(r)$. (4) The Green function of $\bar{g} - \kappa\nabla^2$ in three dimensions is the Yukawa form.[91] ∎ Point 5 is not part of the proof: it is computed under T23 in the local approximation. Under H-R (25.7) the stiffness $e^{(2)}(n) = 1/K^{(2)}\big(t(n)\big)$ is positive at every density, so the divergence in point 5 is an artefact of the cubic truncation; the truncation departs by more than 10 % at $\big|\delta\big| = 0.1$.

Status: points 1–4 proven under H-G1 and the quadratic energy of T23, and known; point 5 computed under T23 (input), local approximation. Sources: (Yukawa 1935; the general rule that exchange through a scalar field attracts like sources is textbook).[92] Computed on a periodic net of 64^3 places (Appendix A.16).

Reading. Maxwell's form survives: the energy falls by exactly the field energy, $E_{\min} = -W$. But no intrinsic energy C is needed and no field energy density is negative. The negative part sits in the coupling term $-s\delta$, on the sources; it equals twice the field energy. The difficulty arose because Maxwell took the energy of the medium as a function of the field alone, obtained from

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[90] A. Berman and R.J. Plemmons, *Nonnegative Matrices in the Mathematical Sciences*, SIAM, 1994, Ch. 6 (inverse-positivity of non-singular M-matrices).

[91] H. Yukawa, "On the interaction of elementary particles. I", *Proc. Phys.-Math. Soc. Japan* 17, 1935, 48–57.

[92] A. Zee, *Quantum Field Theory in a Nutshell*, Princeton University Press, 2003, Chapters I.4 "From Field to Particle to Force" and I.5 "Coulomb and Newton: Repulsion and Attraction".

the case of two like magnetic poles by reversing the sign of the force ($E = C - E'$). A net with positive field energy and a separate linear coupling to its sources gives attraction directly. This split is known: it is the localisation $-\rho\Phi + \left|\nabla\Phi\right|^2/8\pi G$ of Newtonian gravitational energy proposed by Ohanian and by Lynden-Bell and Katz and derived by Bengtsson and Eklund (2022, equations 7 and 22).[93] Status: known; stiffness of the net is a reading (read).

Conditions this places on the net. Three conditions follow. They are open.

- **O1 sharpened.** Newton's $1/r$ holds only at distances well below the range $\ell = \sqrt{\kappa/\bar{g}}$. Under Theorem B15 (25.7) $\bar{g} = 1.2771$ in units of the count: not zero. The range is finite, and κ must greatly exceed $\bar{g}$ times the square of the largest distance, counted in steps, over which $1/r^2$ is observed. κ is not derived. Whether the range meets the scale of the acceleration threshold a_0 is open. Under H-R the coupling is fixed: $\gamma = -3.9365$ (B15).
- **One sign of mass.** Universal attraction needs all sources of one sign. In the net this is the statement that every closed knot shifts the visit density with the same sign. It is not derived.
- **Light.** If light couples to δ only as Nordström's scalar theory couples it, light is not deflected.[94] The Cassini measurement gives $\gamma_{\mathrm{PPN}} = 1 + (2.1 \pm 2.3) \times 10^{-5}$, consistent with general relativity ($\gamma = 1$).[95] A net reading must therefore give light an effective index $n = 1 - 2\Phi/c^2$, twice the value $n = 1 - \Phi/c^2$ that the time part of the metric alone gives (Einstein 1911); the spatial part supplies the other half.[96] Chapter 25.8 reduces this to one hypothesis (Theorem B16).

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[93] I. Bengtsson and T. Eklund, "Energy in Newtonian gravity", *Found. Phys.* 53, 15 (2023; online 2022), doi:10.1007/s10701-022-00660-z, arXiv:2112.06503, equations (1), (7) and (22), with Maxwell's remark quoted.

[94] G. Nordström, "Zur Theorie der Gravitation vom Standpunkt des Relativitätsprinzips", *Ann. Phys.* 42, 1913, 533–554; J.D. Norton, "Einstein, Nordström and the early demise of scalar, Lorentz-covariant theories of gravitation", *Arch. Hist. Exact Sci.* 45, 1992, 17–94.

[95] B. Bertotti, L. Iess and P. Tortora, "A test of general relativity using radio links with the Cassini spacecraft", *Nature* 425, 2003, 374–376.

[96] R. Narayan and M. Bartelmann, "Lectures on gravitational lensing", arXiv:astro-ph/9606001, §2.1.1; P. Schneider, J. Ehlers and E.E. Falco, *Gravitational Lenses*, Springer, 1992.

Sakharov proposed in 1967 that gravity is the elasticity of the vacuum, induced by its fluctuations.[97] B14 is consistent with that reading for the static, scalar part. It does not give the tensor part, and so not general relativity.

25.7 Lever and coupling are one number (O1, IX.1)

Setting. By N1 and N6 there is only the strand and the light location moving on it. The density at a place is how often the location passes it. Let N be the number of visits of a free path to one place (Foundations T24), with cumulant generating function $K(t) = \ln \mathbb{E}\, e^{tN}$ and cumulants $\kappa_1, \kappa_2, \kappa_3$.

Hypothesis H-R. The energy density of the net at density n is the rate function of the visit count: the Legendre transform: $e(n)$ is the largest value, over t, of $tn - K(t)$.

Theorem B15 (Lever = coupling). Under H-R, at the reference state $\bar{n} = \kappa_1$:

1. The stiffness is $\bar{g} = e^{(2)}(\bar{n}) = 1/\kappa_2$.
2. The coupling of Foundations T23, $\gamma = e^{(3)}(\bar{n})\,\bar{n}/e^{(2)}(\bar{n})$, equals the lever of the count: $\gamma = -\kappa_1\kappa_3/\kappa_2^2$.
3. For the free path in three dimensions: $\gamma = -(1 + P_3)/P_3 = -3.9365$ and $\bar{g} = (1 - P_3)^2/P_3 = 1.2771$. In the cubic form of T23, $g_2 = \bar{g}(1 - \gamma) = 6.3043 > 0$; this is a coefficient of the truncation, not a property of the rate function, which is defined only for $n \geq 1$ ($\delta \geq -P_3$).

Here $e^{(k)}$ is the k-th derivative of e.

Proof. For strictly convex K the supremum is reached where $n = K^{(1)}(t)$. Differentiating $e^{(1)}(n) = t(n)$ gives $e^{(2)}(n) = 1/K^{(2)}(t)$ and $e^{(3)}(n) = -K^{(3)}(t)/K^{(2)}(t)^3$. At $t = 0$ the derivatives of K are the cumulants $\kappa_1, \kappa_2, \kappa_3$. Hence $\bar{g} = 1/\kappa_2$ and $\gamma = (-\kappa_3/\kappa_2^3)\,\kappa_1\,\kappa_2 = -\kappa_1\kappa_3/\kappa_2^2$. Point 3 uses the cumulants of the geometric count (Foundations T24). ∎

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[97] A.D. Sakharov, "Vacuum quantum fluctuations in curved space and the theory of gravitation", *Dokl. Akad. Nauk SSSR* 177(1), 1967, 70–71; English reprint *Gen. Relativ. Gravit.* 32, 2000, 365–367.

Status: proven under H-R and T24. The relations between the derivatives of a rate function and the cumulants are known (Cramér; Gärtner–Ellis).[98] Checked symbolically and by a separate numerical Legendre transform (Appendix A.17).

Reading. Under N1 the net has no energy of its own beside the strand. An energy can only measure how far a count departs from its typical value. The rate function is that measure. H-R is one candidate reading of energy in a theory that has only a path. It is not derived from N1–N7. Status of the reading: read.

Consequence. $\bar{g}$ is positive and finite. A free path in three dimensions does not return with certainty, so the spread of its visit count is finite. The static coupling of 25.6 then has finite range (Yukawa), not an exact $1/r$. A path that returns with certainty, as in one or two dimensions, visits a place infinitely often; the count has no cumulant generating function, and $\bar{g} = 1/\kappa_2$ tends to 0 only as a limit (for the count up to step T, as $T \to \infty$).

25.8 Light deflection as refraction (Snellius)

Setting. By N6 light moves one step per tick at every place. By N7 a step and a tick are counts on the strand, not independent quantities. Near a source let one local step measure $1 - \varphi_S$ reference steps and one local tick measure $1 + \varphi_T$ reference ticks, both taken against a distant reference.

Hypothesis H-S. $\varphi_S = \varphi_T = \varphi$: near a source the step is shorter and the tick longer, in reference units, by the same fraction. A common scaling of step and tick ($\varphi_S = -\varphi_T$) gives no deflection. H-S is the strand form of $\gamma_{\mathrm{PPN}} = 1$; it is not derived from N6 or N7. The tick shift φ_T is the gravitational redshift, here taken as input.

Theorem B16 (Deflection). Under N6 and H-S the light location, seen from the distant reference, moves at speed $(1 - \varphi)/(1 + \varphi) \approx 1 - 2\varphi$. It is refracted as by a graded index $n = 1 + 2\varphi$. With $\varphi = GM/(rc^2)$ (Newtonian potential, input) the deflection of a ray at closest distance b is

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[98] H. Cramér, "Sur un nouveau théorème-limite de la théorie des probabilités", *Actualités Scientifiques et Industrielles* 736, 1938, 5–23; H. Touchette, "The large deviation approach to statistical mechanics", *Phys. Rep.* 478, 2009, 1–69, arXiv:0804.0327.

$$\hat{\alpha} = \frac{4GM}{c^2 b}.$$

At the limb of the Sun this is 1.7512″. With $\varphi_S = 0$ (time shift only) it is 0.8756″. With $\varphi_S = -\varphi_T$ (Nordström) it is zero.

Proof. Locally one step per tick (N6). A step that counts $1 - \varphi$ reference steps and a tick that counts $1 + \varphi$ reference ticks give the reference speed $(1 - \varphi)/(1 + \varphi)$, hence $n = 1 + 2\varphi$ to first order. Snell's law in a graded index gives the bending rate $\nabla_\perp n$ along the ray. The integral of $\nabla_\perp (2GM/rc^2)$ along a straight line at distance b is $4GM/(c^2 b)$. ∎

Status: proven under N6, H-S and the Newtonian potential (input); known (the effective-index treatment of lensing).[99] The measured value fits general relativity: $\gamma_{\mathrm{PPN}} = 1 + (2.1 \pm 2.3) \times 10^{-5}$.[100] H-S is input, fixed by the measured γ_{PPN}. Snellius found the law of refraction in Leiden around 1621; Descartes published it in 1637.[101] Computed in Appendix A.18.

The perihelion shift of Mercury is not covered by B16. It needs the second-order terms of the field.

25.9 Gravity and electromagnetism as one field; the numbers that remain

One field, two registers. The quaternion form of 25.1 has a scalar register and a vector register. Electromagnetism lives in the vector register: meetings, with **i**, **j**, **k** (B9). The static coupling of 25.6 lives in a scalar: the visit density. The reading of the net is that the static part of gravity is the scalar register of the same strand. Two facts fit this reading; a third constrains it:

- The sign differs. Under the scalar coupling like sources attract (B14); under the vector coupling like charges repel.

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[99] R. Narayan and M. Bartelmann, "Lectures on gravitational lensing", arXiv:astro-ph/9606001, §2.1.1; P. Schneider, J. Ehlers and E.E. Falco, *Gravitational Lenses*, Springer, 1992.

[100] B. Bertotti, L. Iess and P. Tortora, "A test of general relativity using radio links with the Cassini spacecraft", *Nature* 425, 2003, 374–376.

[101] "Snel (Snellius or Snel van Royen), Willebrord", *Dictionary of Scientific Biography*, via MacTutor (St Andrews); Encyclopedia.com, "Willebrord Snell".

- All matter couples alike. Every loop is made of the same strand, so every loop may shift the visit density in the same way (not derived; see "One sign of mass", 25.6). MICROSCOPE finds no difference between titanium and platinum to 10^{-15}.[102]
- The weak field of gravity has the form of Maxwell's equations (gravitoelectromagnetism), with a magnetic part that a scalar alone does not have.[103] Gravity Probe B measured it: frame dragging -37.2 ± 7.2 mas per year against -39.2 predicted.[104] A scalar register must therefore be joined by a vector part; this is open, with the tensor part.

A residual of ordinary electric forces is excluded. Such a force would depend on composition, against MICROSCOPE. A derivation of gravity from electromagnetic zero-point fluctuations (Puthoff 1989) contained a serious computational error; corrected, the force is nongravitational and negligible (Carlip 1993). Puthoff replied that physical cutoffs restore the inverse-square law (1993).[105] Status: read.

The ratio 10^{-37} is not a separate number. For two protons

$$\frac{F_{\text{grav}}}{F_{\text{el}}} = \frac{G m_p^2}{e^2/4\pi\varepsilon_0} = \frac{\left(m_p/m_{\text{Pl}}\right)^2}{\alpha} = 8.0936 \times 10^{-37},$$

with $m_{\text{Pl}} = \sqrt{\hbar c/G}$. *Proof.* Insert $m_{\text{Pl}}^2 = \hbar c/G$ and $\alpha = e^2/\left(4\pi\varepsilon_0 \hbar c\right)$. ∎ Status: proven (identity); known. Besides α only the length ratio $m_{\text{Pl}}/m_p = 1.3012 \times 10^{19}$ remains; for the electron it is 2.3892×10^{22}. If one step of the strand is the Planck length (identification, not derived), these are the lengths of the proton and electron loops in steps. Gravity is then weak because the loops are long.

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[102] P. Touboul et al., *Phys. Rev. Lett.* 129, 2022, 121102.

[103] B. Mashhoon, "Gravitoelectromagnetism: a brief review", arXiv:gr-qc/0311030.

[104] C.W.F. Everitt et al., "Gravity Probe B: final results of a space experiment to test general relativity", *Phys. Rev. Lett.* 106, 2011, 221101, arXiv:1105.3456.

[105] H.E. Puthoff, "Gravity as a zero-point-fluctuation force", *Phys. Rev. A* 39, 1989, 2333–2342; S. Carlip, "Comment on 'Gravity as a zero-point-fluctuation force'", *Phys. Rev. A* 47, 1993, 3452–3453; H.E. Puthoff, reply, *Phys. Rev. A* 47, 1993, 3454.

What the net must still produce. By N7 only dimensionless numbers are targets.

Number	Value	Reduced to	Status
α	1/137.035999	—	open (O7)
m_p/m_e and the other mass ratios	1836.15267	ratios of closed loop lengths (I1, N6)	open (O3)
$F_{\mathsf{grav}}/F_{\mathsf{el}}$	8.09×10^{-37}	α and m_{Pl}/m_p	reduced
$\bar{g}$	1.2771	H-R, T24	proven under H-R and T24
κ	—	—	open
θ (reversal per step, B10)	—	loop length	open
$a_0/\left(cH_0\right)$	about $1.11/2\pi$	—	read as $1/2\pi$

The speed of light, Planck's constant and the gravitational constant are not targets. They convert between human references (N7).

26. Links That Stay Open

In short.

- The open links attempted in Chapter 25 are listed here.
- Chapter 28 fixes a test for each open question (R1–R29).

The following links were attempted and did not close. No numerical fit is presented as a derivation; under the protocol a fit counts as a fit (G4), not as a law.

Link	Attempt	Why it stays open
O5 remainder	Theorems B9, B13	The coefficients K, C, μ, the force law and H-Q2 are not derived. H-Q1 is reduced to H-Q1′ (order of a meeting as a sign); closure alone cannot give the product (B13).
O6 remainder	Theorem B10	Three space dimensions with four components; hypothesis H-D1.
β in P1	—	The factor $\alpha/4\pi$ is input.
2π turn in a_0	—	The turn per mesh is read, not derived.

Link	Attempt	Why it stays open
O1 Lever = coupling	Theorems B14, B15	Closed under H-R (energy = rate function of the visit count) and T24 (free walk, d = 3). Open: H-R itself, κ, and whether the finite range $\sqrt{\kappa/\bar{g}}$ meets the scale of a_0.
O3 Mass spectrum, $m_p/m_e = 1836.15$, charge	Search for a closure count that yields the ratio	No derivation. Agreement of a number with a formula found after the fact would be a fit.
O4 One state variable	Join χ_a and χ_Φ	No common definition proven.
O7 Fine-structure constant	As O3	No derivation.
O8 Hubble constant or turn	N7	By N7 only $a_0/(cH_0)$ is a target; its value $1/2\pi$ is read, not derived.

Link	Attempt	Why it stays open
General relativity	Theorems B14, B16	Sign of gravity and light deflection follow under named hypotheses (H-G1, H-S). H-S is input (γ_PPN = 1; the redshift enters as φ_T). Open: perihelion shift, gravitomagnetism (frame dragging), the tensor part, one sign of mass.
O3, O7 and 10^{-37}	25.9	10^{-37} reduced to α and m_{Pl}/m_p. α and the mass ratios (ratios of closed loop lengths) not derived.
Nuclear binding and decay	—	Not derived.
Cluster bonding (borides)	Ring closure (B11) covers rings, not polyhedra	Open.
Climate feedbacks	—	Values are input.
Property values of single compounds	—	Measurements.

27. Method: the Respondent–Judge Protocol

In short.

- Each family of claims was checked by an independent judge with its own code; Foundations T21 was not judged (App. D).
- Every number was recomputed; every qualitative claim about the state of science was checked against a second source.

This book follows the Respondent–Judge protocol (v1.0, Konstapel 2026).[106] Its core rules, as applied here:

- **Respondent and judge.** The respondent writes the derivations. A separate judge, per family of claims, writes its own code and fixes its own test ranges before it reads the respondent's work. Then it reads every proof, re-derives each step and searches the literature.
- **One verdict per claim.** VERIFIED, VERIFIED-WITH-FIXES, REFUTED, GAP or KNOWN-ALREADY, each with numbers, counterexamples or sources.
- **Status words.** proven, computed, input, translated, read, open, known, refuted ("corresponded" of protocol v1.0 split into "translated" and "read"). "New" is a note, not a status.
- **Third computation.** Every main result is recomputed a third time with new code (G8).
- **Attestation.** The one human act is the attestation of the result by the author.

The verdicts are listed in Appendix D.

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[106] J. Konstapel, "The Respondent–Judge Protocol", v1.0, Constable Research, Leiden, 17 October 2026, constable.blog.

28. Research Agenda

In short.

- Twenty-nine questions, each with a test fixed in advance.
- The largest: α and 1836.

This chapter defines what remains to be found. Each item states the question, the criterion that counts as a solution, and the data the answer must meet. The criterion is fixed here, before any attempt. A result that is tuned to the number afterwards counts as a fit (G4), not as a derivation.

28.1 Rules for every item

- The rule that produces the number is stated in full before the number is computed.
- The rule uses only N1–N7 and hypotheses named in this book.
- A number counts as reproduced only within the stated tolerance; where none is stated, within the measurement error.
- The computation is repeated by an independent judge with new code.
- A miss is recorded as a miss.

28.2 The numbers

No.	Question	Solution criterion	Data to meet	Present state
R1	Why is $\alpha = 1/137.035999$?	A count of closures that gives α to the measured precision without an adjustable factor	CODATA 2018: $1/\alpha = 137.035999084(21)$	Open (O7)
R2	Why is $m_p/m_e = 1836.15267$?	A rule for the lengths of closed loops (one loop for the electron, a closure of three windings for the proton, 15.5) whose ratio gives the value to the measured precision	CODATA 2018: 1836.15267343(11)	Open (O3); read as a ratio of loop lengths (25.9)
R3	Why are the charges of the three parts of the proton $+2/3, +2/3, -1/3$?	A derivation from the window of three that gives these values and excludes others	Observed charges of all hadrons	Open; read (15.5)

No.	Question	Solution criterion	Data to meet	Present state
R4	Why is the electron one loop and the proton three windings?	A classification of the stable closures of the strand with their multiplicity	The stable particles: electron, proton, the neutrinos, the photon, and their mirrors (the free neutron decays)	Open
R5	Can the released tension at a closure be counted?	A rule that gives, to the measured precision, the hydrogen value relative to the electron mass and the helium-4 value relative to the proton mass	$13.6057/510,998.95 = 2.6626 \times 10^{-5} = \alpha^2/2$ (Rydberg energy; the measured 13.598 eV includes the reduced mass); $28.2956/938.272 = 3.016\,\%$	Open; hydrogen follows from α (R1) and, through the reduced mass, m_p/m_e (R2)
R6	The factor $\beta = \alpha/4\pi$ in P1	A derivation of β	— (sets the size of P1)	Input

No.	Question	Solution criterion	Data to meet	Present state
R7	Nuclear decay and the magic numbers	A closure rule that gives the stable nuclei and their decay modes	Nuclide chart	Open (15.4)

28.3 The hypotheses

No.	Hypothesis to derive	Solution criterion	Data to meet	Present state
R8	H-R: the energy of the net is the rate function of the visit count (25.7)	A derivation of H-R from N1–N7	Must give $\gamma = -3.9365$, $\bar{g} = 1.2771$ (B15)	Read (candidate reading, 25.7)
R9	H-S: near a source the step is shorter and the tick longer by the same fraction (25.8)	A derivation from N1–N7	$\gamma_{\mathrm{PPN}} = 1 + (2.1 \pm 2.3) \times 10^{-5}$ (Cassini)	Input
R10	H-G1: the sources of gravity couple linearly to the visit density (25.6)	A derivation from N1–N7	Universality of free fall to 10^{-15}	Hypothesis
R11	H-Q1′: a meeting records its order as a sign ε (25.5)	A derivation from N3 with $\varepsilon = +1$ for the cyclic order	Hamilton's product	Open
R12	H-Q2 and the coefficients K, C, μ (25.1)	Flatness of the net and the values of the coefficients from N1–N7	$c^2 = 1/(K\mu)$ = one step per tick	Open

No.	Hypothesis to derive	Solution criterion	Data to meet	Present state
R13	H-D1: amplitudes are complex numbers (25.2)	A derivation from re-entry (1.2)	Interference of single particles	Input
R14	Dirac in three space dimensions with four components	The quantum walk of 25.2 extended to three dimensions with the correct dispersion and spin	Relativistic dispersion; spin ½	Open (O6)
R15	The trit rule at the ends of the strand	A definition that removes the GAP of 2.3, at the ends and in the ambiguous case $\sigma(f+1) = \sigma(f-1)$	—	Open

28.4 Gravity

No.	Question	Solution criterion	Data to meet	Present state
R16	Is the range $\sqrt{\kappa/\bar{g}}$ of the static coupling the scale of a_0?	κ from the net such that $\sqrt{\kappa/\bar{g}}$ reproduces a_0 within $\pm 0.24 \times 10^{-10}$ m s^{-2} while $1/r^2$ holds within solar-system bounds	$a_0 = 1.2 \times 10^{-10}$ m s^{-2} (SPARC); solar-system tests of $1/r^2$	Open
R17	Why has all mass one sign?	A proof that every stable closure shifts the visit density the same way	Universality of free fall to 10^{-15}	Open
R18	The vector part of gravity	A derivation of frame dragging giving -39.2 mas per year within ± 7.2	Gravity Probe B: -37.2 ± 7.2 mas per year	Open

No.	Question	Solution criterion	Data to meet	Present state
R19	The perihelion shift	A second-order field from the net giving 43″ per century within the measurement error	Mercury: 43″ per century	Open
R20	Lorentz invariance at the scale of one step	A bound on the dependence of the light speed on energy from the step structure	Fermi GRB 090510: a linear dependence is excluded for a scale below 1.2 Planck energies (App. I)	Open

28.5 Chemistry

No.	Question	Solution criterion	Data to meet	Present state
R21	The Madelung order and its exceptions	A derivation of the filling order from closure counts	Ground-state configurations of all elements (Cr, Cu and the other exceptions)	Input (B2)
R22	The ground state of O_2 and other orbital effects	A closure reading that gives the triplet ground state	O_2 is paramagnetic (triplet)	Open
R23	Cluster bonding (boranes, borides)	Closure on polyhedra, extending B11	Wade’s rules for boranes	Open

28.6 The planet

No.	Question	Solution criterion	Data to meet	Present state
R24	The coefficient 5.35 W m⁻²	A derivation without the idealisations H1–H4 of 25.4	5.35 W m⁻² (radiative transfer)	Input; B12 gives 6.9–7.8
R25	The climate feedbacks	A state function $\lambda(\chi)$ with a value for the present state	λ = 1.31 W m⁻² K⁻¹ for a sensitivity of 3 °C (23.4)	Input
R26	The windings of the Sun and the planets as counts	The periods of 23.8 as ratios from the net	11 years; 41,000, 100,000 and 405,000 years	Open

28.7 The whole net

No.	Question	Solution criterion	Data to meet	Present state
R27	The dynamics of the whole net (Ninth Edition, IX.2)	An evolution rule for the strand from N1–N7	All of the above	Open
R28	One state variable (O4)	A common definition of χ_a and χ_Φ	P1 and C5 with one χ	Open
R29	The value or turn behind H_0 (O8)	$a_0/(cH_0)$ from the net	$a_0/(cH_0) \approx 1.11/2\pi$	Read as $1/2\pi$

Appendix A — Exact Calculations

All calculations were run on 6 November 2026 with exact integer and rational arithmetic where the values are rational, and with 40-digit decimals otherwise. The record of the checks is in Appendix B.

A.1 Radix economy

The cost per unit of $\ln N$ of writing N in radix r tends to $r/\ln r$:

r	$r/\ln r$
2	2.885
e	2.718
3	2.731
4	2.885

A.2 Windows

Enumeration of $\{-1, 0, 1\}^3$: 27 windows. Closed ($x + y + z \equiv 0 \bmod 3$): 9. Of these, 3 homogeneous and 6 heterogeneous. Open: 18, all with exactly two equal trits. Seams over all 81 ordered pairs of closed windows: 9 with no open window, 36 with one, 36 with two.

A.3 Elementary closures

All words of length 1 to 9: 9,841 closed words. Each reduces to nothing by removing standings, meetings and rings; no open word does. Words of length $n = 3$ to 8 that close in every window: 9 for each n.

Necklace counts:

$$g(n) = \frac{1}{n} \sum_{d \mid n} \varphi\left(n/d\right) 3^d: \quad 3,\ 6,\ 11,\ 24,\ 51,\ 130\,.$$

Capacities $\left(3^n - 1\right)/2$: 1, 4, 13, 40, 121.

Eisenstein digit map: box $|a|, |b| \le 40$: 1,788 of 6,561 end in the turn (27.3 %); box $|a|, |b| \le 100$: 16,546 of 40,401 (41.0 %).

A.4 Closure depths and the comma

Continued fraction of $\log_2 3$ (40 digits):

$$[1; 1, 1, 2, 2, 3, 1, 5, 2, 23, 2, 2, 1, 1, 55, 1, \ldots]$$

Denominators of the convergents: 1, 2, 5, 12, 41, 53, 306, 665, 15601, 31867, 79335, 111202, 190537.

Comma:

$$\frac{3^{12}}{2^{19}} = \frac{531441}{524288} = 1.0136432647\ldots, \qquad 1200 \log_2 \frac{3^{12}}{2^{19}} = 23.4600 \text{ cents}.$$

Lever of the free path, $\gamma = -\left(1 + P_d\right)/P_d$:

d	P_d	γ
3	0.3405373	−3.9365
4	0.1932017	−6.1759
5	0.1351786	−8.3976

A.5 Units and the hydrogen spectrum

Inputs (CODATA 2018): $R_\infty = 10,973,731.568160$ m^{-1}; $m_p/m_e = 1836.15267343$; $c = 299,792,458$ m s^{-1}; $h = 6.62607015 \times 10^{-34}$ J s; $e = 1.602176634 \times 10^{-19}$ C.

$$R_H = \frac{R_\infty}{1 + m_e/m_p} = 10,967,758.3403 \text{ m}^{-1}$$

$$S_0 = \frac{1}{2R_H} = 4.55881671 \times 10^{-8} \text{ m}, \qquad T_0 = \frac{S_0}{c} = 1.52065757 \times 10^{-16} \text{ s}$$

$$E_0 = \frac{h}{T_0} = 27.19657453 \text{ eV}, \qquad \frac{E_0}{2} = 13.598287 \text{ eV}$$

Balmer lines, $1/\lambda = R_H\left(1/4 - 1/n^2\right)$, vacuum:

n	λ (nm)
3	656.4696
4	486.2738
5	434.1730
6	410.2935

$9S_0 = 410.294$ nm, equal to the $n = 6$ line because $R_H\left(1/4 - 1/36\right) = 2R_H/9$.

A.6 Gravitation

H_0 in s^{-1} is $H_0 \times 1000/\left(3.0856775814913673 \times 10^{22}\right)$.

H_0	$a_0 = cH_0/2\pi$ (m s^{-2})
67.4	1.042×10^{-10}
70.0	1.082×10^{-10}
73.0	1.129×10^{-10}

Solar edge with $GM_\odot = 1.32712440018 \times 10^{20}$ $\text{m}^3\ \text{s}^{-2}$ and 1 AU equal to $1.495978707 \times 10^{11}$ m:

$$r = \sqrt{GM_\odot/a_0}\text{:} \quad 7,402 \text{ AU } \left(a_0 = 1.082 \times 10^{-10}\right), \qquad 7,030 \text{ AU } \left(a_0 = 1.2 \times 10^{-10}\right).$$

White dwarf G191-B2B: $\Delta\chi_\Phi = GM/\left(Rc^2\right)$ with $M = 1.0 \times 10^{30}$ kg, $R = 1.4 \times 10^7$ m gives 5.304×10^{-5}. $\beta = \alpha/4\pi = 5.807 \times 10^{-4}$. Product: 3.08×10^{-8}.

A.7 Shells and periods

Shell capacity $2\sum_{l=0}^{n-1}\left(2l+1\right)=2n^2$: 2, 8, 18, 32.

Madelung order (sort by $n+l$, then n): 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, 7p. Grouping from each *s* subshell to the next gives period lengths 2, 8, 8, 18, 18, 32, 32. Sum: 118.

A.8 Molecules

Valences used: H 1, C 4, N 3, O 2.

Compound	Valence sum	B = sum/2	N	$R+\Pi=B-N+1$
H_2O	4	2	3	0
CO_2	8	4	3	2
CH_4	8	4	5	0
NH_3	6	3	4	0
C_2H_6O	16	8	9	0
C_6H_6	30	15	12	4
$C_6H_{12}O_6$	48	24	24	1
$C_8H_{10}N_4O_2$	58	29	24	6

Radical check: NO: 3 + 2 = 5 (odd). NO_2: 3 + 2 + 2 = 7 (odd).

Chirality: $4!/\left|T\right|=24/12=2$, with $\left|T\right|=12$ the order of the rotation group of the tetrahedron.

A.9 Radiation

$k=1.380649\times10^{-23}$ J K^{-1} (exact).

$$\sigma = \frac{2\pi^5 k^4}{15 h^3 c^2} = 5.6703744 \times 10^{-8}\ \mathrm{W\ m^{-2} K^{-4}}$$

Wien: x solves $(x-5)e^x + 5 = 0$, $x = 4.9651$; $b = hc/(kx) = 2.89777 \times 10^{-3}$ m K. Peaks: Sun (5,772 K) 0.502 µm; Earth (254.6 K) 11.38 µm.

Effective temperature with $S = 1361$ W m⁻² and $A = 0.30$:

$$T_e = \left(\frac{S(1-A)}{4\sigma}\right)^{1/4} = 254.58\ \mathrm{K}\,.$$

A.10 Climate change

$$\Delta F_{\mathrm{CO_2}} = 5.35 \ln \frac{423.9}{278} = 2.257\ \mathrm{W\ m^{-2}}, \qquad 5.35 \ln 2 = 3.708\ \mathrm{W\ m^{-2}}$$

$$4\sigma T_e^3 = 3.742\ \mathrm{W\ m^{-2} K^{-1}}, \qquad \Delta T_{2\times,\,\text{no feedback}} = \frac{3.93}{3.742} = 1.05\ \mathrm{K}$$

$$\lambda = \frac{3.93}{3.0} = 1.31\ \mathrm{W\ m^{-2} K^{-1}}, \qquad \frac{423.9}{278} = 1.525\,.$$

A.11 Field from closure (B9)

Quaternion form. Periodic net of $4 \times 5 \times 3$ places; integer fields drawn at random (seed 7); one forward step difference in each direction for (1)–(4); for the wave the symmetric second difference $\sum D^b D^f$, with $\omega = 2\sqrt{\sum \sin^2(k/2)}/\sqrt{K\mu}$ (a forward difference applied twice gives a complex ω, for example $0.9879\,|k| + 0.048i$). Exact integer results: $\nabla \nabla q = -\sum D^2 q$ for an arbitrary quaternion field (all four components); $S\,\nabla \mathfrak{B} = 0$ with $\mathfrak{B} = V\,\nabla \mathfrak{A}$; $S\,\nabla V\,\nabla \mathfrak{H} = 0$; $V\,\nabla \nabla \Psi = 0$; $\mathfrak{B}$ unchanged under $\mathfrak{A} \to \mathfrak{A} + \nabla\lambda$; change of $S\,\nabla \mathfrak{A}$ equal to $-\sum D^2 \lambda$. Counterexample: forward differences the first time and backward differences the second time violate (1). Waves: for $k = (0.3, 0.2, 0.1)$ the lattice speed $\omega/|k|$ is 0.997087 at $K\mu = 1$ and 0.664725 at $K\mu = 2.25$, against $1/\sqrt{K\mu}$ = 1 and 0.666667 in the limit.

Cell-complex form, for comparison. Periodic lattice 5^4, random real phases on all edges: largest $|dF|$ 2.7×10^{-15}; gauge change 1.8×10^{-15}; continuity 1.2×10^{-14}. Integer incidence matrices on a periodic 3^4 lattice: $d_1 d_0 = 0$ and $d_2 d_1 = 0$ exactly.

A.12 Motion from reversal (B10)

$\det U = 1$ and $\mathrm{tr} U = 2\cos k \cos\theta$ (symbolic). Over 41 values of k in $[-\pi, \pi]$ and 16 values of θ in $[0, 1.5]$, the largest deviation of $\cos\omega$ from $\cos\theta\cos k$ is 3.9×10^{-16}. Series: $2\left(1 - \cos m\varepsilon \cos p\varepsilon\right)/\varepsilon^2 = p^2 + m^2 - \varepsilon^2\left(m^4/12 + m^2 p^2/2 + p^4/12\right) + O\left(\varepsilon^3\right)$. For $p = 0.7$, $m = 0.4$: ω/ε = 0.806064, 0.806211, 0.806224, 0.806226 for ε = 0.1, 0.03, 0.01, 0.003; $\sqrt{p^2 + m^2} = 0.806226$.

A.13 Ring closure (B11)

Direct diagonalisation of the ring matrix agrees with $-2t\cos(2\pi m/N)$ for $N = 3$ to 14 (and $N = 4, 5, 6, 8$ exactly in a third computation). Closed-shell π counts below the full ring: $N = 6$: 2, 6, 10; $N = 8$: 2, 6, 10, 14. At $N = 1000$ the levels span $[-2t, 2t]$ with largest spacing $0.012566\,t$.

A.14 Logarithmic forcing (B12)

$B(\nu, T) = 2hc^2\nu^3/\left(e^{hc\nu/kT} - 1\right)$ per unit wavenumber at $\nu = 667$ cm^{-1}.

$\alpha = 2\pi w\left[B\left(T_s\right) - B\left(T_t\right)\right]$: 6.908 W m^{-2} ($w$ = 12.5, 288 K, 217 K); 7.350 (13.3, 288, 217); 7.809 (12.5, 289, 205); 7.374 (w = 0.40 THz = 13.3426 cm^{-1}, 288, 217). Per doubling: 4.789, 5.095, 5.412.

A.15 Windows and Hamilton's units (B13)

All 27 windows enumerated; 9 closed. Closure under place-by-place addition mod 3: yes. Order of every non-zero closed window: 3. Map of the six heterogeneous windows: axis = place of the 0, sign = the trit after it in cyclic order; bijective onto $\pm\mathbf{i}, \pm\mathbf{j}, \pm\mathbf{k}$. Negation and cyclic shift preserved: yes. Sums of the 24 ordered pairs of units on different axes: 12 give a unit on the third axis, 12 do not. Examples: $\mathbf{i} + \mathbf{j} \mapsto -\mathbf{k}$, $\left(-\mathbf{i}\right) + \left(-\mathbf{j}\right) \mapsto \mathbf{k}$, $\mathbf{i} + (-\mathbf{k})$ no unit. Script: grav/hq1.py.

A.16 Static coupling of sources (B14)

Periodic net 64^3, lattice Laplacian, solved exactly by discrete Fourier transform; $\kappa = 1$. Interaction energy $U(r) = E(q_1, q_2) - E(q_1) - E(q_2)$ for $q_1 = q_2 = 1$ along one axis.

r	$U, \bar{g} = 0.05$	Yukawa $-e^{-r/\ell}/4\pi r$, $\ell = 4.472$	$U, \bar{g} = 0$ (zero mode removed)	$-1/4\pi r$
2	−0.02835	−0.02544	−0.03936	−0.03979
4	−0.00847	−0.00813	−0.01677	−0.01989
8	−0.00169	−0.00166	−0.00650	−0.00995
16	−0.00014	−0.00014	−0.00163	−0.00497

At short range the lattice differs from the continuum (11 % at $r = 2$). At $\bar{g} = 0$ the periodic box shifts the values; at 128^3 they move towards $-1/4\pi r$: −0.04113, −0.01853, −0.00823, −0.00324 at r = 2, 4, 8, 16. Opposite sources at $r = 4$, $\bar{g} = 0.05$: $U = +0.00847$ (repulsion). The $\bar{g} = 0$ shift is the known periodic-box (Ewald) correction, $G_L(r) \approx 1/4\pi r - 2.8373/(4\pi L) + r^2/(6L^3)$; after it the 64^3 and 128^3 values agree with $1/4\pi r$ within 2.4 % for $r \geq 4$ (0.2 % at $r = 16$, 128^3). The $\bar{g} = 0$ column lies outside point 1 of B14: with the zero mode removed, G has zero sum and is negative on 73 % of the 64^3 box. At $\bar{g} = 0.05$ the residual of about 1.2 % for $r \geq 8$ comes from the lattice decay rate $\operatorname{acosh}(1 + \bar{g}/2) = 0.22314$ against $1/\ell = 0.22361$. Two sources at $r = 8$: field energy $W = 0.23613$, coupling term $-\sum s\delta = -0.47226$, total $-0.23613 = -W$. Crossover of T23 at $\gamma = 2\pi$: $\delta = -1/2\pi = -0.15915$. Scripts: grav/scalar_grav.py, grav/l128.py.

A.17 Lever and coupling (B15)

Geometric count $N \geq 1$ with $\Pr(N = k) = (1 - P)P^{k-1}$; $K(t) = \ln\left[(1 - P)e^t/(1 - Pe^t)\right]$. Symbolic (sympy): $e^{(3)}\kappa_1/e^{(2)}$ with $e^{(2)} = 1/K^{(2)}$, $e^{(3)} = -K^{(3)}/(K^{(2)})^3$ equals $-\kappa_1\kappa_3/\kappa_2^2$ identically in t and P. At $P_3 = 0.3405373$, $t = 0$: $\gamma = -3.93654$. Independent check: numerical Legendre transform (largest value over t of $tn - K(t)$) by root finding (mpmath), numerical

second and third derivatives at $\bar{n} = 1/\left(1 - P_3\right)$: $\gamma = -3.9365359$.
$\bar{g} = \left(1 - P_3\right)^2/P_3 = 1.277073$; $g_2 = \bar{g}\left(1 - \gamma\right) = 6.304318$. Script: grav/bridge.py.

A.18 Deflection by refraction (B16)

$GM_\odot = 1.32712440018 \times 10^{20}$ m³ s⁻², $c = 299,792,458$ m s⁻¹, $b = R_\odot = 6.957 \times 10^8$ m.
$\hat{\alpha} = k\left(GM/c^2 b\right) \int_{-\infty}^{\infty} \left(1 + u^2\right)^{-3/2} du = 2kGM/\left(c^2 b\right)$ for $n = 1 + kGM/\left(rc^2\right)$. Numerical integral 2.000000. $k = 1$: 0.875595″; $k = 2$: 1.751190″.

A.19 Ratio of gravity to electric force (25.9)

CODATA 2018: $G = 6.67430 \times 10^{-11}$, $m_p = 1.67262192 \times 10^{-27}$ kg,
$m_e = 9.1093837 \times 10^{-31}$ kg, $k_e = 8.9875517923 \times 10^9$, $e = 1.602176634 \times 10^{-19}$ C,
$\hbar = 1.054571817 \times 10^{-34}$ J s, $\alpha = 0.0072973525693$. $Gm_p^2/\left(k_e e^2\right) = 8.093551 \times 10^{-37}$;
$\left(m_p/m_{\mathrm{Pl}}\right)^2/\alpha = 8.093551 \times 10^{-37}$; $m_p/m_{\mathrm{Pl}} = 7.685148 \times 10^{-20}$;
$m_{\mathrm{Pl}}/m_p = 1.301211 \times 10^{19}$; $m_{\mathrm{Pl}}/m_e = 2.389222 \times 10^{22}$.

A.20 External influences (23.8)

$\Delta F = \Delta S(1 - A)/4$, $A = 0.30$: 0.175 W m⁻² ($\Delta S = 1.0$), 0.245 ($\Delta S = 1.4$). Global annual mean insolation $S/\left(4\sqrt{1 - e^2}\right)$ with $S = 1361$: 340.2975 at $e = 0.0167$, 340.25 at $e = 0$, difference 0.0475 W m⁻². Present $de/dt = -4.2 \times 10^{-5}$ per century gives -2.4×10^{-4} W m⁻² per century. The global annual mean is independent of obliquity and precession (judge's numerical check: 340.306 W m⁻² at obliquity 22.1° and 24.5°, perihelion longitude 0° and 90°). Tides relative to the Moon, $\left(M/d^3\right)/\left(M_{\mathrm{Moon}}/d_{\mathrm{Moon}}^3\right)$, $d_{\mathrm{Moon}} = 3.844 \times 10^8$ m: Sun 0.484, Venus 6.86×10^{-5}, Mars 3.05×10^{-6}, Jupiter 7.12×10^{-6}, Saturn 2.56×10^{-7}. 405-kyr cycle: $g_2 - g_5 = \left(7.452 - 4.257\right)''$/yr gives 405.6 kyr.

A.21 Released tension (15.7)

CODATA 2018 masses in MeV: proton 938.27208816, neutron 939.56542052, helium-4 nucleus 3727.3794066. $2m_p + 2m_n - m_\alpha = 28.2956$ MeV, 0.7534 % of the sum of the parts. Hydrogen: ionisation energy 13.598 eV (Rydberg energy 13.6057 eV, reduced-mass corrected 13.5983 eV).

Appendix B — Record of the Checks

Item	Method	Result	Agrees with source
Foundations T3, T4, T11	Exhaustive enumeration	9; 3 + 6; 18; 9/36/36	Ninth Edition
Foundations T7, T8	All words, lengths 1–9 and 3–8	Reduction iff closed; 9 per length	Ninth Edition
Foundations T13	Burnside formula	3, 6, 11, 24, 51, 130	Ninth Edition
Foundations T14	Digit map, two boxes	27.3 %, 41.0 %	Ninth Edition
Foundations T17, T18	40-digit continued fraction; exact fraction	List and comma as printed	Ninth Edition; Khinchin
Foundations T24	Formula with Watson/Montroll values	−3.9365, −6.1759, −8.3976	Ninth Edition
Physics III.2	40-digit decimals	Table of Chapter 11	Ninth Edition
Physics I3, P1, P3	Stated inputs	As Chapters 13–14	Ninth Edition
B1, B2	Symbolic sum; sorting	$2n^2$; 2, 8, 8, 18, 18, 32, 32	IUPAC table (118 elements)
B3, B4	Graph counts	Table A.8	PubChem formulas; standard texts
B5	Group order	2	Standard stereochemistry

Item	Method	Result	Agrees with source
σ, Wien, T_e	40-digit decimals	Appendix A.9	CODATA; Trenberth et al. 2009
CO_2 forcing, sensitivity	Stated inputs	Appendix A.10	IPCC TAR, AR6; WMO 2025
B7, B8, B4 on Wikipedia lists	Script over 1,183 entries	Appendix C; Chapter 19.6	Wikipedia; pymatgen element table
Source errors found	Second source	Furosemide $C_{12}H_{11}ClN_2O_5S$; $Eu_2(CO_3)_3$; Cu_2SO_4	Merck Index; Wikipedia articles
B9–B12	Respondent, judge and third computation (G8) with new code	A.11–A.14	Yee 1966; Wilson 1974; Feynman–Hibbs; Hückel 1931; Romps et al. 2022; Wordsworth et al. 2024
PubChem count	Two publications	118,596,691 (2024); 119 million (2025)	NAR 2025 table and abstract
ECS 3 °C (2.5–4)	Two sources	Agree	IPCC AR6 Ch. 7; MPI-M; IPSL
CO_2 423.9 ppm (2024)	Two sources	Agree	WMO 2025; national reports citing WMO

Item	Method	Result	Agrees with source
Warming 2024 / 2025	Two sources	1.55 / 1.44 °C	WMO 2025 update; WMO 2026 report

The calculation script (Python 3, mpmath) is kept with the manuscript and reproduces every number in Appendix A.

Appendix C — Closure Check of the Wikipedia Compound Lists

Source: Wikipedia, *List of inorganic compounds* and *Dictionary of chemical formulas*, read on 6 November 2026 as far as the reading tool reached (see Chapter 19.6). Names and formulas are given as printed in the source; “(as printed)” marks an entry whose printed name or formula is doubtful. Electrons: total electron count of the formula unit minus its charge (B7). Closure: whether oxidation states from the pymatgen element table, with 0 allowed only for an element standing alone, can sum to the charge of the formula (B8); the result depends on that table. $R + \Pi$: rings plus extra bond orders for molecules built only from H, B, C, N, O, F, Si, P, S, Cl, Br, I and Se, with the valences of Theorem B4.

C.1 Inorganic compounds

Name	Formula	Electrons	Closure	Oxidation states	Note
Actinium(III) chloride	$AcCl_3$	140	yes	Ac+3 Cl-1	
Actinium(III) fluoride	AcF_3	116	yes	Ac+3 F-1	
Actinium(III) oxide	Ac_2O_3	202	yes	Ac+3 O-2	
Actinium(III) sulfide	Ac_2S_3	226	yes	Ac+3 S-2	
Actinium(III) nitrate	$Ac(NO_3)_3$	182	yes	Ac+3 N+5 O-2	
Actinium(III) bromide	$AcBr_3$	194	yes	Ac+3 Br-1	
Actinium(III) hydroxide	$Ac(OH)_3$	116	yes	Ac+3 O-2 H+1	
Actinium(III) iodide	AcI_3	248	yes	Ac+3 I-1	
Actinium(III) phosphate	$AcPO_4$	136	yes	Ac+3 P+5 O-2	
Aluminium antimonide	AlSb	64	yes	Al+3 Sb-3	
Aluminium arsenate	$AlAsO_4$	78	yes	Al+3 As+5 O-2	
Aluminium arsenide	AlAs	46	yes	Al+3 As-3	

Name	Formula	Electrons	Closure	Oxidation states	Note
Aluminium diboride	AlB_2	23	no (pymatgen table)		boron-rich
Aluminium bromide	$AlBr_3$	118	yes	Al+3 Br-1	
Aluminium carbide	Al_4C_3	70	yes	Al+3 C-4	
Aluminium iodide	AlI_3	172	yes	Al+3 I-1	
Aluminium nitride	AlN	20	yes	Al+3 N-3	
Aluminium oxide	Al_2O_3	50	yes	Al+3 O-2	
Aluminium phosphide	AlP	28	yes	Al+3 P-3	
Aluminium chloride	$AlCl_3$	64	yes	Al+3 Cl-1	
Aluminium fluoride	AlF_3	40	yes	Al+3 F-1	
Aluminium hydroxide	$Al(OH)_3$	40	yes	Al+3 O-2 H+1	
Aluminium nitrate	$Al(NO_3)_3$	106	yes	Al+3 N+5 O-2	
Aluminium sulfide	Al_2S_3	74	yes	Al+3 S-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Aluminium sulfate	$Al_2(SO_4)_3$	170	yes	Al+3 S+6 O-2	
Aluminium potassium sulfate	$KAl(SO_4)_2$	128	yes	K+1 Al+3 S+6 O-2	
Aluminium hydride	AlH_3	16	yes	Al+3 H-1	
Americium (II) bromide	$AmBr_2$	165	yes, rarer states	Am+2 Br-1	
Americium (III) bromide	$AmBr_3$	200	yes	Am+3 Br-1	
Americium (II) chloride	$AmCl_2$	129	yes, rarer states	Am+2 Cl-1	
Americium (III) chloride	$AmCl_3$	146	yes	Am+3 Cl-1	
Americium (III) fluoride	AmF_3	122	yes	Am+3 F-1	
Americium (IV) fluoride	AmF_4	131	yes, rarer states	Am+4 F-1	
Americium (II) iodide	AmI_2	201	yes, rarer states	Am+2 I-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Americium (III) iodide	AmI_3	254	yes	Am+3 I-1	
Americium dioxide	AmO_2	111	yes, rarer states	Am+4 O-2	
Ammonia	NH_3	10	yes	N-3 H+1	
Ammonium azide	$[NH_4]N_3$	32	yes	N-1 H+1	
Ammonium bicarbonate	$[NH_4]HCO_3$	42	yes	N-3 H+1 C+4 O-2	
Ammonium bisulfate	$[NH_4]HSO_4$	60	yes	N+5 H+1 S-2 O-2	ionic or expanded valence
Ammonium bromide	NH_4Br	46	yes	N-3 H+1 Br-1	ionic or expanded valence
Ammonium chromate	$[NH_4]_2CrO_4$	78	yes	N-3 H+1 Cr+6 O-2	
Ammonium cerium(IV) nitrate	$[NH_4]_2[Ce(NO_3)_6]$	266	yes	N+3 H+1 Ce+4 O-2	
Ammonium cerium(IV) sulfate	$[NH_4]_4[Ce(SO_4)_4]$	294	yes	N+5 H+1 Ce+4 S-2 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Ammonium chloride	$[NH_4]Cl$	28	yes	N-3 H+1 Cl-1	ionic or expanded valence
Ammonium chlorate	$[NH_4]ClO_3$	52	yes	N+3 H+1 Cl-1 O-2	ionic or expanded valence
Ammonium cyanide	$[NH_4]CN$	24	yes	N-3 H+1 C+2	
Ammonium dichromate	$[NH_4]_2Cr_2O_7$	126	yes	N-3 H+1 Cr+6 O-2	
Ammonium dihydrogen phosphate	$[NH_4]H_2PO_4$	60	yes	N-3 H+1 P+5 O-2	ionic or expanded valence
Ammonium hexafluoroaluminate	$AlF_6H_{12}N_3$	100	yes	Al+3 F-1 H+1 N-3	
Ammonium hexafluorophosphate	F_6H_4NP	80	yes	F-1 H+1 N-3 P+5	ionic or expanded valence
Ammonium hexachloroplatinate	$[NH_4]_2[PtCl_6]$	202	yes	N-3 H+1 Pt+4 Cl-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Ammonium hydroxide	$[NH_4]OH$	20	yes	N-3 H+1 O-2	ionic or expanded valence
Ammonium nitrate	$[NH_4]NO_3$	42	yes	N+1 H+1 O-2	
Ammonium orthomolybdate	$[NH_4]_2MoO_4$	96	yes	N-3 H+1 Mo+6 O-2	
Ammonium sulfamate	$[NH_4]SO_3NH_2$	60	yes	N+1 H+1 S-2 O-2	ionic or expanded valence
Ammonium sulfide	$[NH_4]_2S$	38	yes	N-3 H+1 S-2	ionic or expanded valence
Ammonium sulfite	$[NH_4]_2SO_3$	62	yes	N-3 H+1 S+4 O-2	ionic or expanded valence
Ammonium sulfate	$[NH_4]_2SO_4$	70	yes	N+1 H+1 S-2 O-2	ionic or expanded valence
Ammonium perchlorate	$[NH_4]ClO_4$	60	yes	N+5 H+1 Cl-1 O-2	ionic or expanded valence

Name	Formula	Electrons	Closure	Oxidation states	Note
Ammonium permanganate	$[NH_4]MnO_4$	68	yes	N-3 H+1 Mn+7 O-2	
Ammonium persulfate	$[NH_4]_2S_2O_8$	118	yes	N-2 H+1 S+6 O-2	ionic or expanded valence
Ammonium diamminetetrathiocyanatochromate(III)	$[NH_4][Cr(SCN)_4(NH_3)_2]$	171	yes	N-3 H+1 Cr+3 S-2 C+4	
Ammonium thiocyanate	$[NH_4]SCN$	40	yes	N-3 H+1 S-2 C+4	
Ammonium triiodide	$[NH_4][I_3]$	170	yes	N-1 H+1 I-1	ionic or expanded valence
Diammonium dioxido(dioxo)molybdenum	$H_8MoN_2O_4$	96	yes	H+1 Mo+6 N-3 O-2	
Diammonium phosphate	$[NH_4]_2HPO_4$	70	yes	N-3 H+1 P+5 O-2	ionic or expanded valence

Name	Formula	Electrons	Closure	Oxidation states	Note
Tetramethylammonium perchlorate	$[N(CH_3)_4]ClO_4$	92	yes	N+5 C-2 H+1 Cl-1 O-2	ionic or expanded valence
Antimony hydride (stibine)	SbH_3	54	yes	Sb-3 H+1	
Antimony pentachloride	$SbCl_5$	136	yes	Sb+5 Cl-1	
Antimony pentafluoride	SbF_5	96	yes	Sb+5 F-1	
Antimony potassium tartrate	$K_2Sb_2(C_4H_2O_6)_2$	288	yes	K+1 Sb-3 C+3 H+1 O-2	
Antimony sulfate	$Sb_2(SO_4)_3$	246	yes	Sb+3 S+6 O-2	
Antimony trichloride	$SbCl_3$	102	yes	Sb+3 Cl-1	
Antimony trifluoride	SbF_3	78	yes	Sb+3 F-1	
Antimony trioxide	Sb_2O_3	126	yes	Sb+3 O-2	
Antimony trisulfide	Sb_2S_3	150	yes	Sb+3 S-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Antimony pentasulfide	Sb_2S_5	182	yes	Sb+5 S-2	
Argon fluorohydride	HArF	28	no (pymatgen table)		noble-gas compound
Arsenic trifluoride	AsF_3	60	yes	As+3 F-1	
Arsenic triiodide	AsI_3	192	yes	As+3 I-1	
Arsenic pentafluoride	AsF_5	78	yes	As+5 F-1	
Arsenic trioxide	As_2O_3	90	yes	As+3 O-2	
Arsenous acid	$As(OH)_3$	60	yes	As+3 O-2 H+1	
Arsenic acid	$AsO(OH)_3$	68	yes	As+5 O-2 H+1	
Arsine	AsH_3	36	yes	As-3 H+1	
Barium azide	$Ba(N_3)_2$	98	mixed valence	Ba+2 N-0.333	
Barium bromide	$BaBr_2$	126	yes	Ba+2 Br-1	
Barium carbonate	$BaCO_3$	86	yes	Ba+2 C+4 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Barium chlorate	$Ba(ClO_3)_2$	138	yes, rarer states	Ba+2 Cl+5 O-2	
Barium chloride	$BaCl_2$	90	yes	Ba+2 Cl-1	
Barium chromate	$BaCrO_4$	112	yes	Ba+2 Cr+6 O-2	
Barium ferrate	$BaFeO_4$	114	yes, rarer states	Ba+2 Fe+6 O-2	
Barium ferrite	$BaFe_{12}O_{19}$	520	yes	Ba+2 Fe+3 O-2	
Barium fluoride	BaF_2	74	yes	Ba+2 F-1	
Barium hydroxide	$Ba(OH)_2$	74	yes	Ba+2 O-2 H+1	
Barium hexaboride	BaB_6	86	no (pymatgen table)		boron-rich
Barium iodide	BaI_2	162	yes	Ba+2 I-1	
Barium manganate	$BaMnO_4$	113	yes, rarer states	Ba+2 Mn+6 O-2	
Barium nitrate	$Ba(NO_3)_2$	118	yes	Ba+2 N+5 O-2	
Barium oxalate	BaC_2O_4	100	yes	Ba+2 C+3 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Barium oxide	BaO	64	yes	Ba+2 O-2	
Barium permanganate	$Ba(MnO_4)_2$	170	yes	Ba+2 Mn+7 O-2	
Barium peroxide	BaO_2	72	yes, rarer states	Ba+2 O-1	
Barium sulfate	$BaSO_4$	104	yes	Ba+2 S+6 O-2	
Barium sulfide	BaS	72	yes	Ba+2 S-2	
Barium titanate	$BaTiO_3$	102	yes	Ba+2 Ti+4 O-2	
Barium thiocyanate	$Ba(SCN)_2$	114	yes	Ba+2 S-2 C+4 N-3	
Beryllium borohydride	$Be(BH_4)_2$	22	yes	Be+2 B+3 H-1	
Beryllium bromide	$BeBr_2$	74	yes	Be+2 Br-1	
Beryllium carbonate	$BeCO_3$	34	yes	Be+2 C+4 O-2	
Beryllium chloride	$BeCl_2$	38	yes	Be+2 Cl-1	
Beryllium fluoride	BeF_2	22	yes	Be+2 F-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Beryllium hydride	BeH_2	6	yes	Be+2 H-1	
Beryllium hydroxide	$Be(OH)_2$	22	yes	Be+2 O-2 H+1	
Beryllium iodide	BeI_2	110	yes	Be+2 I-1	
Beryllium nitrate	$Be(NO_3)_2$	66	yes	Be+2 N+5 O-2	
Beryllium nitride	Be_3N_2	26	yes	Be+2 N-3	
Beryllium oxide	BeO	12	yes	Be+2 O-2	
Beryllium sulfate	$BeSO_4$	52	yes	Be+2 S+6 O-2	
Beryllium sulfide	BeS	20	yes	Be+2 S-2	
Beryllium telluride	BeTe	56	yes	Be+2 Te-2	
Bismuth chloride	$BiCl_3$	134	yes	Bi+3 Cl-1	
Bismuth ferrite	$BiFeO_3$	133	yes	Bi+3 Fe+3 O-2	
Bismuth hydroxide	BiH_3O_3	110	yes	Bi+3 H+1 O-2	
Bismuth(III) iodide	BiI_3	242	yes	Bi+3 I-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Bismuth(III) nitrate	BiN_3O_9	176	yes	Bi+3 N+5 O-2	
Bismuth(III) oxide	Bi_2O_3	190	yes	Bi+3 O-2	
Bismuth oxychloride	BiOCl	108	yes	Bi+3 O-2 Cl-1	
Bismuth pentafluoride	BiF_5	128	yes	Bi+5 F-1	
Bismuth(III) sulfide	Bi_2S_3	214	yes	Bi+3 S-2	
Bismuth(III) telluride	Bi_2Te_3	322	yes	Bi+3 Te-2	
Bismuth tribromide	$BiBr_3$	188	yes	Bi+3 Br-1	
Bismuth tungstate	Bi_2WO_6	288	yes	Bi+3 W+6 O-2	
Borane	BH_3	8	yes	B-3 H+1	
Borax	$Na_2B_4O_7(H_2O)_{10}$	198	yes	Na+1 B+3 O-2 H+1	
Borazine	$B_3H_6N_3$	42	yes	B+3 H-1 N-1	
Borazocine	$B_4H_8N_4$	56	yes	B+3 H-1 N-1	
Boric acid	H_3BO_3	32	yes	H+1 B+3 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Boron carbide	B_4C	26	yes, rarer states	B+1 C-4	
Boron nitride	BN	12	yes	B+3 N-3	
Boron phosphate	BPO_4	52	yes	B+3 P+5 O-2	
Boron phosphide	BP	20	yes	B+3 P-3	
Boron suboxide	B_6O	38	no (pymatgen table)		boron-rich
Boron tribromide	BBr_3	110	yes	B+3 Br-1	
Boron trichloride	BCl_3	56	yes	B+3 Cl-1	
Boron trifluoride	BF_3	32	yes	B+3 F-1	
Boron triiodide	BI_3	164	yes	B+3 I-1	
Boron oxide	B_2O_3	34	yes	B+3 O-2	
Boroxine	$B_3H_3O_3$	42	yes	B+3 H-1 O-2	
Bromine monochloride	BrCl	52	yes, rarer states	Br+1 Cl-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Bromine pentafluoride	BrF_5	80	yes	Br+5 F-1	ionic or expanded valence
Bromic acid	$HBrO_3$	60	yes	H+1 Br+5 O-2	
Bromine monoxide	Br_2O	78	yes, rarer states	Br+1 O-2	
Bromine trifluoride	BrF_3	62	yes, rarer states	Br+3 F-1	ionic or expanded valence
Bromine monofluoride	BrF	44	yes, rarer states	Br+1 F-1	
Bismuth(III) fluoride	BiF_3	110	yes	Bi+3 F-1	
Bis(pentafluorosulfanyl) peroxide	F_5SOOSF_5	138	yes, rarer states	F-1 S+6 O-1	ionic or expanded valence
Calcium hexaboride	CaB_6	50	no (pymatgen table)		boron-rich
Calcium bromide	$CaBr_2$	90	yes	Ca+2 Br-1	
Carbon tetrabromide	CBr_4	146	yes	C+4 Br-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Cadmium arsenide	Cd_3As_2	210	yes	Cd+2 As-3	
Cadmium bromide	$CdBr_2$	118	yes	Cd+2 Br-1	
Cadmium chloride	$CdCl_2$	82	yes	Cd+2 Cl-1	
Cadmium fluoride	CdF_2	66	yes	Cd+2 F-1	
Cadmium iodide	CdI_2	154	yes	Cd+2 I-1	
Cadmium nitrate	$Cd(NO_3)_2$	110	yes	Cd+2 N+5 O-2	
Cadmium oxide	CdO	56	yes	Cd+2 O-2	
Cadmium phosphide	Cd_3P_2	174	yes	Cd+2 P-3	
Cadmium selenide	CdSe	82	yes	Cd+2 Se-2	
Cadmium sulfate	$CdSO_4$	96	yes	Cd+2 S+6 O-2	
Cadmium sulfide	CdS	64	yes	Cd+2 S-2	
Cadmium telluride	CdTe	100	yes	Cd+2 Te-2	
Caesium bicarbonate	$CsHCO_3$	86	yes	Cs+1 H+1 C+4 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Caesium bromide	CsBr	90	yes	Cs+1 Br-1	
Caesium carbonate	Cs_2CO_3	140	yes	Cs+1 C+4 O-2	
Caesium chloride	CsCl	72	yes	Cs+1 Cl-1	
Caesium chromate	Cs_2CrO_4	166	yes	Cs+1 Cr+6 O-2	
Caesium dichloroiodate	$CsICl_2$	142	yes, rarer states	Cs+1 I+1 Cl-1	
Caesium dodecaborate	$Cs_2B_{12}H_{12}$	182	no (pymatgen table)		boron-rich
Caesium fluoride	CsF	64	yes	Cs+1 F-1	
Caesium heptafluoroxenate	$CsXeF_7$	172	yes	Cs+1 Xe+6 F-1	
Caesium hydride	CsH	56	yes	Cs+1 H-1	
Caesium hydrogen sulfate	$CsHSO_4$	104	yes	Cs+1 H+1 S+6 O-2	
Caesium iodide	CsI	108	yes	Cs+1 I-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Caesium monoxide	Cs_2O	118	yes	Cs+1 O-2	
Caesium nitrate	$CsNO_3$	86	yes	Cs+1 N+5 O-2	
Caesium ozonide	CsO_3	79	mixed valence, rarer states	Cs+1 O-0.333	
Caesium perchlorate	$CsClO_4$	104	yes, rarer states	Cs+1 Cl+7 O-2	
Caesium peroxide	Cs_2O_2	126	yes, rarer states	Cs+1 O-1	
Caesium sulfate	Cs_2SO_4	158	yes	Cs+1 S+6 O-2	
Caesium superoxide	CsO_2	71	mixed valence, rarer states	Cs+1 O-0.5	
Caesium triiodide	CsI_3	214	mixed valence, rarer states	Cs+1 I-0.333	
Californium(III) bromide	$CfBr_3$	203	yes	Cf+3 Br-1	
Californium(III) carbonate	$Cf_2(CO_3)_3$	286	yes	Cf+3 C+4 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Californium(III) chloride	$CfCl_3$	149	yes	Cf+3 Cl-1	
Californium(III) fluoride	CfF_3	125	yes	Cf+3 F-1	
Californium(III) iodide	CfI_3	257	yes	Cf+3 I-1	
Californium(II) iodide	CfI_2	204	yes, rarer states	Cf+2 I-1	
Californium(III) nitrate	$Cf(NO_3)_3$	191	yes	Cf+3 N+5 O-2	
Californium(III) oxide	Cf_2O_3	220	yes	Cf+3 O-2	
Californium(III) phosphate	$CfPO_4$	145	yes	Cf+3 P+5 O-2	
Californium(III) sulfate	$Cf_2(SO_4)_3$	340	yes	Cf+3 S+6 O-2	
Californium(III) sulfide	Cf_2S_3	244	yes	Cf+3 S-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Californium oxyfluoride	CfOF	115	yes	Cf+3 O-2 F-1	
Californium oxychloride	CfOCl	123	yes	Cf+3 O-2 Cl-1	
Calcium carbide	CaC_2	32	yes	Ca+2 C-1	
Calcium carbonate	$CaCO_3$	50	yes	Ca+2 C+4 O-2	
Calcium chlorate	$Ca(ClO_3)_2$	102	yes, rarer states	Ca+2 Cl+5 O-2	
Calcium chloride	$CaCl_2$	54	yes	Ca+2 Cl-1	
Calcium chromate	$CaCrO_4$	76	yes	Ca+2 Cr+6 O-2	
Calcium cyanamide	$CaCN_2$	40	yes	Ca+2 C+4 N-3	
Calcium fluoride	CaF_2	38	yes	Ca+2 F-1	
Calcium hydride	CaH_2	22	yes	Ca+2 H-1	
Calcium hydroxide	$Ca(OH)_2$	38	yes	Ca+2 O-2 H+1	
Calcium monosilicide	CaSi	34	yes, rarer states	Ca+2 Si-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Calcium oxalate	CaC_2O_4	64	yes	Ca+2 C+3 O-2	
Calcium hydroxychloride	$CaOCl_2$	62	no (pymatgen table)		Cl at +1 and −1
Calcium perchlorate	$Ca(ClO_4)_2$	118	yes, rarer states	Ca+2 Cl+7 O-2	
Calcium permanganate	$Ca(MnO_4)_2$	134	yes	Ca+2 Mn+7 O-2	
Calcium sulfate	$CaSO_4$	68	yes	Ca+2 S+6 O-2	
Calcium thiocyanate	$C_2CaN_2S_2$	78	yes	C+4 Ca+2 N-3 S-2	
Carbon dioxide	CO_2	22	yes	C+4 O-2	
Carbon disulfide	CS_2	38	yes	C+4 S-2	
Carbon monoxide	CO	14	yes	C+2 O-2	
Carbon tetrachloride	CCl_4	74	yes	C+4 Cl-1	
Carbon tetrafluoride	CF_4	42	yes	C+4 F-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Carbon tetraiodide	CI_4	218	yes	C+4 I-1	
Carbonic acid	H_2CO_3	32	yes	H+1 C+4 O-2	
Carbonyl chloride	$COCl_2$	48	yes	C+4 O-2 Cl-1	
Carbonyl fluoride	COF_2	32	yes	C+4 O-2 F-1	
Carbonyl sulfide	COS	30	yes	C+4 O-2 S-2	
Carboplatin	$C_6H_{12}N_2O_4Pt$	172	yes	C-1 H+1 N-1 O-2 Pt+4	
Calcium hypochlorite	$Ca(ClO)_2$	70	yes, rarer states	Ca+2 Cl+1 O-2	
Cerium(IV) sulfate	$Ce(SO_4)_2$	154	yes	Ce+4 S+6 O-2	
Cerium(III, IV) oxide	Ce_3O_4	206	mixed valence, rarer states	Ce+2.67 O-2	
Cerium hexaboride	CeB_6	88	no (pymatgen table)		boron-rich
Cerium aluminium	CeAl	71	no (pymatgen table)		intermetallic

Name	Formula	Electrons	Closure	Oxidation states	Note
Cerium cadmium	CeCd	106	no (pymatgen table)		intermetallic
Cerium magnesium	CeMg	70	no (pymatgen table)		intermetallic
Cerium mercury	CeHg	138	no (pymatgen table)		intermetallic
Cerium silver	CeAg	105	no (pymatgen table)		intermetallic
Cerium thallium	CeTl	139	no (pymatgen table)		intermetallic
Cerium zinc	CeZn	88	no (pymatgen table)		intermetallic
Cerium(III) chloride	$CeCl_3$	109	yes	Ce+3 Cl-1	
Chloramine	NH_2Cl	26	yes	N-1 H+1 Cl-1	
Chloric acid	$HClO_3$	42	yes, rarer states	H+1 Cl+5 O-2	
Chlorine azide	ClN_3	38	yes, rarer states	Cl+3 N-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Chlorine dioxide	ClO_2	33	yes, rarer states	Cl+4 O-2	radical
Chlorine monofluoride	ClF	26	yes, rarer states	Cl+1 F-1	
Chlorine monoxide	ClO	25	yes, rarer states	Cl+2 O-2	radical
Chlorine pentafluoride	ClF_5	62	yes, rarer states	Cl+5 F-1	ionic or expanded valence
Chlorine perchlorate	Cl_2O_4	66	yes, rarer states	Cl+4 O-2	
Chlorine tetroxide	$O_3ClOOClO_3$	98	yes, rarer states	O-1 Cl+4	
Chlorine trifluoride	ClF_3	44	yes, rarer states	Cl+3 F-1	ionic or expanded valence
Chlorine trioxide	ClO_3	41	yes, rarer states	Cl+6 O-2	radical
Chloroplatinic acid	$H_2[PtCl_6]$	182	yes	H+1 Pt+4 Cl-1	
Chlorosulfonic acid	$ClSO_3H$	58	yes	Cl-1 S+6 O-2 H+1	
Chlorosulfonyl isocyanate	$ClSO_2NCO$	70	yes	Cl-1 S-2 O-2 N+5 C+4	

Name	Formula	Electrons	Closure	Oxidation states	Note
Chloryl fluoride	ClO_2F	42	yes, rarer states	Cl+5 O-2 F-1	
Chromium(II) chloride	$CrCl_2$	58	yes	Cr+2 Cl-1	
Chromium(III) chloride	$CrCl_3$	75	yes	Cr+3 Cl-1	
Chromyl chloride	CrO_2Cl_2	74	yes	Cr+6 O-2 Cl-1	
Chromic acid	H_2CrO_4	58	yes	H+1 Cr+6 O-2	
Chromium trioxide	CrO_3	48	yes	Cr+6 O-2	
Chromium(II) sulfate	$CrSO_4$	72	yes	Cr+2 S+6 O-2	
Chromium(III) nitrate	$Cr(NO_3)_3$	117	yes	Cr+3 N+5 O-2	
Chromium(III) oxide	Cr_2O_3	72	yes	Cr+3 O-2	
Chromium(III) sulfate	$Cr_2(SO_4)_3$	192	yes	Cr+3 S+6 O-2	
Chromium(III) telluride	Cr_2Te_3	204	yes	Cr+3 Te-2	
Chromium(IV) oxide	CrO_2	40	yes	Cr+4 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Chromium pentafluoride	CrF_5	69	yes	Cr+5 F-1	
Chromium sulfide bromide	CrSBr	75	yes	Cr+3 S-2 Br-1	
Chromyl fluoride	CrO_2F_2	58	yes	Cr+6 O-2 F-1	
Curium(III) chloride	$CmCl_3$	147	yes	Cm+3 Cl-1	
Curium(III) oxide	Cm_2O_3	216	yes	Cm+3 O-2	
Curium(IV) oxide	CmO_2	112	yes, rarer states	Cm+4 O-2	
Curium hydroxide	$Cm(OH)_3$	123	yes	Cm+3 O-2 H+1	
Cerium(III) fluoride	CeF_3	85	yes	Ce+3 F-1	
Cerium(IV) fluoride	CeF_4	94	yes	Ce+4 F-1	
Chromium(III) fluoride	CrF_3	51	yes	Cr+3 F-1	
Curium(III) fluoride	CmF_3	123	yes	Cm+3 F-1	
Cobalt(II) acetate	$Co(CH_3CO_2)_2$	89	yes	Co+2 C+3 H-1 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Cobalt(II) bromide	$CoBr_2$	97	yes	Co+2 Br-1	
Cobalt(II) carbonate	$CoCO_3$	57	yes	Co+2 C+4 O-2	
Cobalt(II) chloride	$CoCl_2$	61	yes	Co+2 Cl-1	
Cobalt(II) fluoride	CoF_2	45	yes	Co+2 F-1	
Cobalt(II) hydroxide	$Co(OH)_2$	45	yes	Co+2 O-2 H+1	
Cobalt(II) iodide	CoI_2	133	yes	Co+2 I-1	
Cobalt(II) nitrate	$Co(NO_3)_2$	89	yes	Co+2 N+5 O-2	
Cobalt(II) oxide	CoO	35	yes	Co+2 O-2	
Cobalt(II) perchlorate	$Co(ClO_4)_2$	125	yes, rarer states	Co+2 Cl+7 O-2	
Cobalt(II) phosphate	$Co_3(PO_4)_2$	175	yes	Co+2 P+5 O-2	
Cobalt(II) sulfate	$CoSO_4$	75	yes	Co+2 S+6 O-2	
Cobalt(II) thiocyanate	$Co(SCN)_2$	85	yes	Co+2 S-2 C+4 N-3	
Cobalt(II,III) oxide	Co_3O_4	113	mixed valence	Co+2.67 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Cobalt(III) chloride	$CoCl_3$	78	yes	Co+3 Cl-1	
Cobalt(III) fluoride	CoF_3	54	yes	Co+3 F-1	
Cobalt(III) hydroxide	$Co(OH)_3$	54	yes	Co+3 O-2 H+1	
Cobalt(III) nitrate	$Co(NO_3)_3$	120	yes	Co+3 N+5 O-2	
Cobalt(III) oxide	Co_2O_3	78	yes	Co+3 O-2	
Copper(I) acetylide	Cu_2C_2	70	yes	Cu+2 C-2	
Copper(I) azide	CuN_3	50	yes	Cu+3 N-1	
Copper(I) bromide	CuBr	64	yes	Cu+1 Br-1	
Copper(I) chloride	CuCl	46	yes	Cu+1 Cl-1	
Copper(I) fluoride	CuF	38	yes	Cu+1 F-1	
Copper(I) hydroxide	CuOH	38	yes	Cu+1 O-2 H+1	
Copper(I) iodide	CuI	82	yes	Cu+1 I-1	
Copper(I) nitrate	$CuNO_3$	60	yes	Cu+1 N+5 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Copper(I) oxide	Cu_2O	66	yes	Cu+1 O-2	
Copper(I) phosphide	Cu_3P	102	yes	Cu+1 P-3	
Copper(I) selenide	Cu_2Se	92	yes	Cu+1 Se-2	
Copper(I) sulfate (as printed)	$CuSO_4$	77	yes	Cu+2 S+6 O-2	formula and name disagree in source
Copper(I) sulfide	Cu_2S	74	yes	Cu+1 S-2	
Copper(I) telluride	Cu_2Te	110	yes	Cu+1 Te-2	
Copper(I) thiocyanate	CuSCN	58	yes	Cu+1 S-2 C+4 N-3	
Copper(I,II) sulfite	$Cu_3(SO_3)_2$	167	yes	Cu+2 S+3 O-2	
Copper(II) arsenate	$Cu_3(AsO_4)_2$	217	yes	Cu+2 As+5 O-2	
Copper(II) azide	$Cu(N_3)_2$	71	mixed valence	Cu+2 N-0.333	
Copper(II) borate	$Cu_3(BO_3)_2$	145	yes	Cu+2 B+3 O-2	
Copper(II) bromide	$CuBr_2$	99	yes	Cu+2 Br-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Copper(II) carbonate	$CuCO_3$	59	yes	Cu+2 C+4 O-2	
Copper(II) carbonate hydroxide	$Cu_2(CO_3)(OH)_2$	106	yes	Cu+2 C+4 O-2 H+1	
Copper(II) chlorate	$Cu(ClO_3)_2$	111	yes, rarer states	Cu+2 Cl+5 O-2	
Copper(II) chloride	$CuCl_2$	63	yes	Cu+2 Cl-1	
Copper(II) fluoride	CuF_2	47	yes	Cu+2 F-1	
Copper(II) hydroxide	$Cu(OH)_2$	47	yes	Cu+2 O-2 H+1	
Copper(II) nitrate	$Cu(NO_3)_2$	91	yes	Cu+2 N+5 O-2	
Copper(II) oxide	CuO	37	yes	Cu+2 O-2	
Copper(II) perchlorate	$Cu(ClO_4)_2$	127	yes, rarer states	Cu+2 Cl+7 O-2	
Copper(II) phosphate	$Cu_3(PO_4)_2$	181	yes	Cu+2 P+5 O-2	
Copper(II) selenide	CuSe	63	yes	Cu+2 Se-2	
Copper(II) selenite	$CuSeO_3$	87	yes	Cu+2 Se+4 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Copper(II) sulfide	CuS	45	yes	Cu+2 S-2	
Copper(II) telluride	CuTe	81	yes	Cu+2 Te-2	
Copper(II) thiocyanate	$Cu(SCN)_2$	87	yes	Cu+2 S-2 C+4 N-3	
Copper oxychloride	$H_3ClCu_2O_3$	102	yes	H+1 Cl-1 Cu+2 O-2	
Tetrammine copper(II) sulfate	$[Cu(NH_3)_4]SO_4$	117	yes	Cu+2 N-1 H+1 S-2 O-2	
Cyanogen bromide	BrCN	48	yes	Br-1 C+4 N-3	
Cyanogen chloride	ClCN	30	yes	Cl-1 C+4 N-3	
Cyanogen iodide	ICN	66	yes	I-1 C+4 N-3	
Cyanogen	$(CN)_2$	26	yes	C+3 N-3	
Cyanuric chloride	$C_3Cl_3N_3$	90	yes	C+4 Cl-1 N-3	
Cyanogen thiocyanate	CNSCN	42	yes	C+4 N-3 S-2	
Cyanogen selenocyanate	CNSeCN	60	yes	C+4 N-3 Se-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Cyanogen azide	N_3CN	34	yes	N-1 C+4	
Dysprosium(II) chloride	$DyCl_2$	100	yes, rarer states	Dy+2 Cl-1	
Dysprosium(II) iodide	DyI_2	172	yes, rarer states	Dy+2 I-1	
Dysprosium(III) acetate	$Dy(CH_3COO)_3$	159	yes	Dy+3 C+3 H-1 O-2	
Dysprosium(III) bromide	$DyBr_3$	171	yes	Dy+3 Br-1	
Dysprosium(III) carbonate	$Dy_2(CO_3)_3$	222	yes	Dy+3 C+4 O-2	
Dysprosium(III) chloride	$DyCl_3$	117	yes	Dy+3 Cl-1	
Dysprosium(III) fluoride	DyF_3	93	yes	Dy+3 F-1	
Dysprosium(III) iodide	DyI_3	225	yes	Dy+3 I-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Dysprosium(III) nitrate	$Dy(NO_3)_3$	159	yes	Dy+3 N+5 O-2	
Dysprosium(III) oxalate	$Dy_2(C_2O_4)_3$	264	yes	Dy+3 C+3 O-2	
Dysprosium(III) oxide	Dy_2O_3	156	yes	Dy+3 O-2	
Dysprosium(III) phosphate	$DyPO_4$	113	yes	Dy+3 P+5 O-2	
Dysprosium(III) selenide	Dy_2Se_3	234	yes	Dy+3 Se-2	
Dysprosium(III) sulfide	Dy_2S_3	180	yes	Dy+3 S-2	
Dysprosium(III) sulfate	$Dy_2(SO_4)_3$	276	yes	Dy+3 S+6 O-2	
Dysprosium(III) telluride	Dy_2Te_3	288	yes	Dy+3 Te-2	
Dysprosium arsenide	DyAs	99	yes	Dy+3 As-3	

Name	Formula	Electrons	Closure	Oxidation states	Note
Dysprosium bismuthide	DyBi	149	yes, rarer states	Dy+3 Bi-3	
Dysprosium iodate	$Dy(IO_3)_3$	297	yes	Dy+3 I+5 O-2	
Dysprosium monosulfide	DyS	82	yes, rarer states	Dy+2 S-2	
Dysprosium nitride	DyN	73	yes	Dy+3 N-3	
Dysprosium phosphide	DyP	81	yes	Dy+3 P-3	
Dysprosium stannate	$Dy_2Sn_2O_7$	288	yes	Dy+3 Sn+4 O-2	
Dysprosium titanate	$Dy_2Ti_2O_7$	232	yes	Dy+3 Ti+4 O-2	
Einsteinium(III) bromide	$EsBr_3$	204	yes	Es+3 Br-1	
Einsteinium(III) carbonate	$Es_2(CO_3)_3$	288	yes	Es+3 C+4 O-2	
Einsteinium(III) chloride	$EsCl_3$	150	yes	Es+3 Cl-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Einsteinium (III) fluoride	EsF_3	126	yes	Es+3 F-1	
Einsteinium (III) iodide	EsI_3	258	yes	Es+3 I-1	
Einsteinium (III) nitrate	$Es(NO_3)_3$	192	yes	Es+3 N+5 O-2	
Einsteinium (III) oxide	Es_2O_3	222	yes	Es+3 O-2	
Einsteinium (III) phosphate	$EsPO_4$	146	yes	Es+3 P+5 O-2	
Einsteinium (III) sulfate	$Es_2(SO_4)_3$	342	yes	Es+3 S+6 O-2	
Einsteinium (III) sulfide	Es_2S_3	246	yes	Es+3 S-2	
Erbium-copper	ErCu	97	no (pymatgen table)		intermetallic
Erbium-gold	ErAu	147	no (pymatgen table)		intermetallic
Erbium-iridium	ErIr	145	yes, rarer states	Er+3 Ir-3	
Erbium-silver	ErAg	115	no (pymatgen table)		intermetallic

Name	Formula	Electrons	Closure	Oxidation states	Note
Erbium hexaboride	ErB_6	98	no (pymatgen table)		boron-rich
Erbium iodate	$Er(IO_3)_3$	299	yes	Er+3 I+5 O-2	
Erbium nitride	ErN	75	yes	Er+3 N-3	
Erbium oxybromide	ErOBr	111	yes	Er+3 O-2 Br-1	
Erbium oxychloride	ErOCl	93	yes	Er+3 O-2 Cl-1	
Erbium oxyfluoride	ErOF	85	yes	Er+3 O-2 F-1	
Erbium phosphide	ErP	83	yes	Er+3 P-3	
Erbium silicide	$ErSi_2$	96	mixed valence, rarer states	Er+3 Si-1.5	
Erbium tetraboride	ErB_4	88	no (pymatgen table)		boron-rich
Erbium(III) bromide	$ErBr_3$	173	yes	Er+3 Br-1	
Erbium(III) chloride	$ErCl_3$	119	yes	Er+3 Cl-1	
Erbium(III) fluoride	ErF_3	95	yes	Er+3 F-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Erbium(III) hydroxide	$Er(OH)_3$	95	yes	Er+3 O-2 H+1	
Erbium(III) iodide	ErI_3	227	yes	Er+3 I-1	
Erbium(III) nitrate	$Er(NO_3)_3$	161	yes	Er+3 N+5 O-2	
Erbium(III) oxide	Er_2O_3	160	yes	Er+3 O-2	
Erbium(III) selenate	$Er_2(SeO_4)_3$	334	yes	Er+3 Se+6 O-2	
Erbium(III) selenide	Er_2Se_3	238	yes	Er+3 Se-2	
Erbium(III) sulfate	$Er_2(SO_4)_3$	280	yes	Er+3 S+6 O-2	
Erbium(III) telluride	Er_2Te_3	292	yes	Er+3 Te-2	
Europium(II) bromide	$EuBr_2$	133	yes	Eu+2 Br-1	
Europium(II) chloride	$EuCl_2$	97	yes	Eu+2 Cl-1	
Europium(II) fluoride	EuF_2	81	yes	Eu+2 F-1	
Europium(II) hydride	EuH_2	65	yes	Eu+2 H-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Europium(II) hydroxide	$Eu(OH)_2$	81	yes	Eu+2 O-2 H+1	
Europium(II) oxide	EuO	71	yes	Eu+2 O-2	
Europium(II) iodide	EuI_2	169	yes	Eu+2 I-1	
Europium(II) selenide	EuSe	97	yes	Eu+2 Se-2	
Europium(II) silicide	$EuSi_2$	91	yes, rarer states	Eu+2 Si-1	
Europium(II) sulfate	$EuSO_4$	111	yes	Eu+2 S+6 O-2	
Europium(II) sulfide (as printed)	EuS_2	95	yes	Eu+2 S-1	source formula; EuS (not caught by B8)
Europium(II) telluride	EuTe	115	yes	Eu+2 Te-2	
Europium(II) titanate	$EuTiO_3$	109	yes	Eu+2 Ti+4 O-2	
Europium(III) acetate	$Eu(CH_3COO)_3$	156	yes	Eu+3 C+3 H-1 O-2	
Europium(III) arsenate	$EuAsO_4$	128	yes	Eu+3 As+5 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Europium(III) bromide	$EuBr_3$	168	yes	Eu+3 Br-1	
Europium(III) carbonate (as printed)	$Eu(CO_3)_3$	153	yes, rarer states	Eu+3 C+2 O-1	formula and name disagree in source
Europium(III) chloride	$EuCl_3$	114	yes	Eu+3 Cl-1	
Europium(III) chromate	$EuCrO_4$	119	yes	Eu+2 Cr+6 O-2	
Europium(III) fluoride	EuF_3	90	yes	Eu+3 F-1	
Europium(III) hydroxide	$Eu(OH)_3$	90	yes	Eu+3 O-2 H+1	
Europium(III) iodate	$Eu(IO_3)_3$	294	yes	Eu+3 I+5 O-2	
Europium(III) iodide	EuI_3	222	yes	Eu+3 I-1	
Europium(III) nitrate	$Eu(NO_3)_3$	156	yes	Eu+3 N+5 O-2	
Europium(III) oxide	Eu_2O_3	150	yes	Eu+3 O-2	
Europium(III) perchlorate	$Eu(ClO_4)_3$	210	yes, rarer states	Eu+3 Cl+7 O-2	

Name	Formula	Electrons	Closure	Oxidation states	Note
Europium(III) phosphate	$EuPO_4$	110	yes	Eu+3 P+5 O-2	
Europium(III) phosphide	EuP	78	yes	Eu+3 P-3	
Europium(III) selenide	Eu_2Se_3	228	yes	Eu+3 Se-2	
Europium(III) sulfate	$Eu_2(SO_4)_3$	270	yes	Eu+3 S+6 O-2	
Europium(III) telluride	Eu_2Te_3	282	yes	Eu+3 Te-2	
Europium(III) vanadate	$EuVO_4$	118	yes	Eu+3 V+5 O-2	
Europium barium titanate	$BaEuTiO_4$	173	yes	Ba+2 Eu+2 Ti+4 O-2	
Fluoroantimonic acid	H_2FSbF_6	116	yes	H+1 F-1 Sb+5	
Tetrafluorohydrazine	N_2F_4	50	yes, rarer states	N+2 F-1	
Trifluoromethylisocyanide	C_2NF_3	46	yes	C+3 N-3 F-1	
Trifluoromethanesulfonic acid	CF_3SO_3H	74	yes	C+4 F-1 S+4 O-2 H+1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Ammonium fluoride	NH_4F	20	yes	N-3 H+1 F-1	ionic or expanded valence
Ammonium bifluoride	NH_4HF_2	30	yes	N-3 H+1 F-1	ionic or expanded valence
Ammonium tetrafluoroborate	NH_4BF_4	52	yes	N-3 H+1 B+3 F-1	ionic or expanded valence
Dinitrogen difluoride	N_2F_2	32	yes	N+1 F-1	
Dioxygen difluoride	O_2F_2	34	yes, rarer states	O+1 F-1	
Diphosphorus tetrafluoride	P_2F_4	66	yes, rarer states	P+2 F-1	
Disulfur difluoride	S_2F_2	50	yes, rarer states	S+1 F-1	
Fluoroboric acid	HBF_4	42	yes	H+1 B+3 F-1	ionic or expanded valence
Fluorine azide	FN_3	30	mixed valence	F-1 N+0.333	

Name	Formula	Electrons	Closure	Oxidation states	Note
Fluorine fluorosulfate	$FOSO_2F$	58	yes, rarer states	F-1 O-1 S+5	
Fluorine nitrate	FNO_3	40	yes, rarer states	F-1 N+4 O-1	
Fluorosulfuric acid	FSO_3H	50	yes	F-1 S+6 O-2 H+1	
Gadolinium(III) fluoride	GdF_3	91	yes	Gd+3 F-1	
Gallium(III) fluoride	GaF_3	58	yes	Ga+3 F-1	
Germanium tetrafluoride	GeF_4	68	yes	Ge+4 F-1	
Gold(III) fluoride	AuF_3	106	yes	Au+3 F-1	
Hafnium(IV) fluoride	HfF_4	108	yes	Hf+4 F-1	
Hexafluoroantimonic acid (as printed)	H_2SbF_6	107	no (pymatgen table)		source formula; $HSbF_6$ closes
Hexafluorophosphoric acid	HPF_6	70	yes	H+1 P+5 F-1	ionic or expanded valence

Name	Formula	Electrons	Closure	Oxidation states	Note
Hexafluorosilicic acid	H_2SiF_6	70	yes	H+1 Si+4 F-1	ionic or expanded valence
Hexafluorotitanic acid	H_2TiF_6	78	yes	H+1 Ti+4 F-1	
Hydrogen fluoride	HF	10	yes	H+1 F-1	
Hypofluorous acid	HOF	18	yes, rarer states	H-1 O+2 F-1	
Indium(III) fluoride	InF_3	76	yes	In+3 F-1	
Iodine heptafluoride	IF_7	116	yes, rarer states	I+7 F-1	ionic or expanded valence
Iodine monofluoride	IF	62	yes, rarer states	I+1 F-1	
Iodine pentafluoride	IF_5	98	yes	I+5 F-1	ionic or expanded valence
Iridium(III) fluoride	IrF_3	104	yes	Ir+3 F-1	
Iridium(VI) fluoride	IrF_6	131	yes, rarer states	Ir+6 F-1	
Iron(II) fluoride	FeF_2	44	yes	Fe+2 F-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Iron(III) fluoride	FeF_3	53	yes	Fe+3 F-1	
Krypton difluoride	KrF_2	54	yes	Kr+2 F-1	
Lanthanum (III) fluoride	LaF_3	84	yes	La+3 F-1	
Lead(II) fluoride	PbF_2	100	yes	Pb+2 F-1	
Lead(IV) fluoride	PbF_4	118	yes	Pb+4 F-1	
Lithium fluoride	LiF	12	yes	Li+1 F-1	
Magnesium fluoride	MgF_2	30	yes	Mg+2 F-1	
Manganese (II) fluoride	MnF_2	43	yes	Mn+2 F-1	
Manganese (III) fluoride	MnF_3	52	yes	Mn+3 F-1	
Manganese (IV) fluoride	MnF_4	61	yes	Mn+4 F-1	
Mercury(I) fluoride	Hg_2F_2	178	yes	Hg+1 F-1	
Mercury(II) fluoride	HgF_2	98	yes	Hg+2 F-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Molybdenum(III) fluoride	MoF_3	69	yes	Mo+3 F-1	
Molybdenum(V) fluoride	MoF_5	87	yes	Mo+5 F-1	
Molybdenum(VI) fluoride	MoF_6	96	yes	Mo+6 F-1	
Niobium(IV) fluoride	NbF_4	77	yes	Nb+4 F-1	
Niobium(V) fluoride	NbF_5	86	yes	Nb+5 F-1	
Neodymium(III) fluoride	NdF_3	87	yes	Nd+3 F-1	
Nickel(II) fluoride	NiF_2	46	yes	Ni+2 F-1	
Neptunium(IV) fluoride	NpF_4	129	yes, rarer states	Np+4 F-1	
Neptunium(V) fluoride	NpF_5	138	yes	Np+5 F-1	
Neptunium(VI) fluoride	NpF_6	147	yes, rarer states	Np+6 F-1	
Trifluoramine oxide	ONF_3	42	yes	O-2 N+5 F-1	

Name	Formula	Electrons	Closure	Oxidation states	Note
Nitrogen trifluoride	NF_3	34	yes	N+3 F-1	
Nitronium tetrafluoroborate	NO_2BF_4	64	yes	N+5 O-2 B+3 F-1	
Nitrosonium tetrafluoroborate	$NOBF_4$	56	yes	N+3 O-2 B+3 F-1	
Nitrosyl fluoride	NOF	24	yes	N+3 O-2 F-1	
Nitryl fluoride	NO_2F	32	yes	N+5 O-2 F-1	
Osmium(IV) fluoride	OsF_4	112	yes	Os+4 F-1	
Osmium(VI) fluoride	OsF_6	130	yes, rarer states	Os+6 F-1	
Osmium(VII) fluoride	OsF_7	139	yes, rarer states	Os+7 F-1	
Oxygen difluoride	OF_2	26	yes, rarer states	O+2 F-1	

C.2 Organic compounds

Name	Formula	Electrons	Parity	$R + \Pi$	Note
carbonylsilver	CAgO	61	odd	–	open shell
dichlorodifluoromethane	CCl_2F_2	58	even	0	
carbon tetrachloride	CCl_4	74	even	0	
tetracyanomethane	$C(CN)_4$	58	even	8	
trichlorofluoromethane	$CFCl_3$	66	even	0	
chlorotrifluoromethane (as printed)	$CFCl_2CF_2Cl$	90	even	0	
chloroform	$CHCl_3$	58	even	0	
chlorodifluoromethane	$CHClF_2$	42	even	0	
cyanoform	$CH(CN)_3$	46	even	6	
isocyanic acid	CHNO	22	even	2	
trinitromethane	CHN_3O_6	76	even	3	
formate ion	CHO_2^-	24	even	–	
methylene	CH_2	8	even	1	
carbene silver	CH_2Ag	55	odd	–	open shell

Name	Formula	Electrons	Parity	$R + \Pi$	Note
1,3-butadiene	$CH_2CHCHCH_2$	30	even	2	
ketene	CH_2CO	22	even	2	
ethenol	CH_2CHOH	24	even	1	
chloroacetic acid	$CH_2ClCOOH$	48	even	1	
dichloromethane	CH_2Cl_2	42	even	0	
chlorofluoromethane	CH_2ClF	34	even	0	
malononitrile	$CH_2(CN)_2$	34	even	4	
formaldehyde	CH_2O	16	even	1	
methanediol	$CH_2(OH)_2$	26	even	0	
ethylene glycol	CH_2OHCH_2OH	34	even	0	
propyne	CH_3CCH	22	even	2	
dimethylcadmium	CH_3CdCH_3	66	even	–	
2-butene	$CH_3CHCHCH_3$	32	even	1	
propene	CH_3CHCH_2	24	even	1	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
acetaldehyde	CH_3CHO	24	even	1	
bromoethane	CH_3CH_2Br	52	even	0	
butan-1-ol	$CH_3CH_2CH_2CH_2OH$	42	even	0	
1-propanol	$CH_3CH_2CH_2OH$	34	even	0	
propanamide	$CH_3CH_2CONH_2$	40	even	1	
propionic acid	CH_3CH_2COOH	40	even	1	
diethyl ether	$CH_3CH_2OCH_2CH_3$	42	even	0	
ethanol	CH_3CH_2OH	26	even	0	
stearic acid	$CH_3(CH_2)_{16}COOH$	160	even	1	
acetonitrile	CH_3CN	22	even	2	
acetone	CH_3COCH_3	32	even	1	
methyl acetate	CH_3COOCH_3	40	even	1	
acetyl chloride	CH_3COCl	40	even	1	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
acetamide	CH_3CONH_2	32	even	1	
acetate ion	CH_3COO^-	32	even	–	
vinyl acetate	$CH_3COOCHCH_2$	46	even	2	
benzyl acetate	$CH_3COOCH_2C_6H_5$	80	even	5	
isoamyl acetate	$CH_3COO(CH_2)_2CH(CH_3)_2$	72	even	1	
acetic acid	CH_3COOH	32	even	1	
sodium acetate	CH_3COONa	42	even	–	
potassium acetate	CH_3COOK	50	even	–	
rubidium acetate	CH_3COORb	68	even	–	
caesium acetate	CH_3COOCs	86	even	–	
acetic anhydride	$(CH_3CO)_2O$	54	even	2	
chloromethane	CH_3Cl	26	even	0	
dimethylmercury	CH_3HgCH_3	98	even	–	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
iodomethane	CH_3I	62	even	0	
dimethyl ether	CH_3OCH_3	26	even	0	
methylamine	CH_3NH_2	18	even	0	
oxaziridine	CH_3NO	24	even	1	
caesium methoxide	CH_3OCs	72	even	–	
methanol	CH_3OH	18	even	0	
potassium methoxide	CH_3OK	36	even	–	
lithium methoxide	CH_3OLi	20	even	–	
sodium methoxide	CH_3ONa	28	even	–	
rubidium methoxide	CH_3ORb	54	even	–	
dimethyl sulfide	CH_3SCH_3	34	even	0	
methanethiol	CH_3SH	26	even	0	
isopropyl alcohol	$(CH_3)_2CHOH$	34	even	0	
dimethyl oxalate	$(CH_3)_2C_2O_4$	62	even	2	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
dimethyl hydrazine	$(CH_3)_2NNH_2$	34	even	0	
dimethylamine	$(CH_3)_2NH$	26	even	0	
dimethylsulfoniopropionate	$(CH_3)_2SCH_2CH_2COO$	72	even	1	
t-butyl chloride	$(CH_3)_3CCl$	50	even	0	
t-butyl alcohol (as printed)	$(CH)_3COH$	36	even	3	
di-t-butyl peroxide	$(CH_3)_3COOC(CH_3)_3$	82	even	0	
trimethylamine	$(CH_3)_3N$	34	even	0	
methane	CH_4	10	even	0	
hydroxycarbamide	$CH_4N_2O_2$	40	even	1	
guanidine	CH_5N_3	32	even	1	
cyanide ion	CN^-	14	even	–	
guanidine nitrate	$C(NH_2)_3NO_3$	64	even	1	
cyanate ion	CNO^-	22	even	–	
carbon trioxide	CO_3	30	even	2	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
carbonate ion	CO_3^{2-}	32	even	–	
tetrafluoroethylene	C_2F_4	48	even	1	
acetylene	C_2H_2	14	even	2	
glyoxal	$C_2H_2O_2$	30	even	2	
vinyl chloride	C_2H_3Cl	32	even	1	
glycolonitrile	C_2H_3NO	30	even	2	
ethylene	C_2H_4	16	even	1	
ethylene dichloride	$C_2H_4Cl_2$	50	even	0	
3-amino-1,2,4-triazole	$C_2H_4N_4$	44	even	3	
ethylene oxide	C_2H_4O	24	even	1	
ethylamine	$C_2H_5NH_2$	26	even	0	
glycine	$C_2H_5NO_2$	40	even	1	
ethoxide ion	$C_2H_5O^-$	26	even	–	
diethylamine	$(C_2H_5)_2NH$	42	even	0	
caesium ethoxide	C_2H_5OCs	80	even	–	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
potassium ethoxide	C_2H_5OK	44	even	–	
sodium ethoxide	C_2H_5ONa	36	even	–	
rubidium ethoxide	C_2H_5ORb	62	even	–	
ethane	C_2H_6	18	even	0	
dimethyl sulfoxide	C_2H_6OS	42	even	0	
ethanolamine	C_2H_7NO	34	even	0	
ammonium acetate	$C_2H_7NO_2$	42	even	0	
taurine	$C_2H_7NO_3S$	66	even	0	
oxalate ion	$C_2O_4^{2-}$	46	even	–	
methyl perchlorate	CH_3ClO_4	58	even	0	
1,1,3-trichloropropene	$C_3H_3Cl_3$	72	even	1	
malonate ion	$C_3H_3O_4^-$	54	even	–	
cyanopolyyne	C_3HN	26	even	4	
azete	C_3H_3N	28	even	3	
propadiene	C_3H_4	22	even	2	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
imidazole	$C_3H_4N_2$	36	even	3	
aminothiazole	$C_3H_4N_2S$	52	even	3	
pyruvic acid	$C_3H_4O_3$	46	even	2	
malonic acid	$C_3H_4O_4$	54	even	2	
acrylamide	C_3H_5NO	38	even	2	
3-amino-1H-pyrazole	$C_3H_5N_3$	44	even	3	
nitroglycerine	$C_3H_5N_3O_9$	116	even	3	
cyclopropane	C_3H_6	24	even	1	
propylene	C_3H_6	24	even	1	
ethyl formate	$C_3H_6O_2$	40	even	1	
2-mercaptopropionic acid	$C_3H_6O_2S$	56	even	1	
3-mercaptopropionic acid	$C_3H_6O_2S$	56	even	1	
azetidine	C_3H_7N	32	even	1	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
n-propyl azide	$C_3H_7N_3$	46	even	2	
alpha-alanine	$C_3H_7NO_2$	48	even	1	
beta-alanine	$C_3H_7NO_2$	48	even	1	
cysteine	$C_3H_7NO_2S$	64	even	1	
serine	$C_3H_7NO_3$	56	even	1	
phosphetane	C_3H_7P	40	even	1	
propane	C_3H_8	26	even	0	
glyphosate	$C_3H_8NO_5P$	88	even	1	
propanol	C_3H_8O	34	even	0	
2-propanol	C_3H_8O	34	even	0	
propylene glycol	$C_3H_8O_2$	42	even	0	
1,3-propanediol	$C_3H_8O_2$	42	even	0	
glycerol	$C_3H_8O_3$	50	even	0	
1,3,5-triazinane	$C_3H_9N_3$	48	even	1	
cyanuric acid	$C_3N_3(OH)_3$	66	even	4	
cyanuric triazide	C_3N_{12}	102	even	10	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
2,6-dichloro-5-fluoropyrimidine (as printed)	$C_4HCl_2FN_2$	82	even	4	
diacetylene	C_4H_2	26	even	4	
diiodobutadiyne	C_4I_2	130	even	4	
5-bromo-2-chloropyrimidine	$C_4H_2BrClN_2$	92	even	4	
2,4-dichloropyrimidine	$C_4H_2Cl_2N_2$	74	even	4	
4,6-dichloropyrimidine	$C_4H_2Cl_2N_2$	74	even	4	
2-amino-4,6-dichloropyrimidine	$C_4H_3Cl_2N_3$	82	even	4	
fluorouracil	$C_4H_3FN_2O_2$	66	even	4	
vinylacetylene	C_4H_4	28	even	3	
flucytosine	$C_4H_4FN_3O$	66	even	4	
uracil	$C_4H_4N_2O_2$	58	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
diaminomaleonitrile	$C_4H_4N_4$	56	even	5	
3-aminopyrazole-4-carbonitrile	$C_4H_4N_4$	56	even	5	
1,3,5,7-tetrazocine	$C_4H_4N_4$	56	even	5	
furan	C_4H_4O	36	even	3	
methyl 2-fluoroacrylate	$C_4H_5FO_2$	54	even	2	
cytosine	$C_4H_5N_3O$	58	even	4	
fomepizole	$C_4H_6N_2$	44	even	3	
1-methylimidazole	$C_4H_6N_2$	44	even	3	
4-methylimidazole	$C_4H_6N_2$	44	even	3	
methimazole	$C_4H_6N_2S$	60	even	3	
2-amino-4-methylthiazole	$C_4H_6N_2S$	60	even	3	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
2,4-diamino-6-hydroxypyrimidine	$C_4H_6N_4O$	66	even	4	
1,4-butynediol	$C_4H_6O_2$	46	even	2	
gamma-butyrolactone	$C_4H_6O_2$	46	even	2	
crotonic acid	$C_4H_6O_2$	46	even	2	
diacetyl	$C_4H_6O_2$	46	even	2	
diepoxybutane	$C_4H_6O_2$	46	even	2	
1,4-dioxene	$C_4H_6O_2$	46	even	2	
isocrotonic acid	$C_4H_6O_2$	46	even	2	
methacrylic acid	$C_4H_6O_2$	46	even	2	
methyl acrylate	$C_4H_6O_2$	46	even	2	
succinaldehyde	$C_4H_6O_2$	46	even	2	
vinyl acetate	$C_4H_6O_2$	46	even	2	
propylene carbonate	$C_4H_6O_3$	54	even	2	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
succinic acid	$C_4H_6O_4$	62	even	2	
2-bromobutyric acid	$C_4H_7BrO_2$	82	even	1	
4-bromobutyric acid	$C_4H_7BrO_2$	82	even	1	
alpha-bromoisobutyric acid	$C_4H_7BrO_2$	82	even	1	
ethyl bromoacetate	$C_4H_7BrO_2$	82	even	1	
potassium oxybate	$C_4H_7KO_3$	74	even	–	
sodium oxybate	$C_4H_7NaO_3$	66	even	–	
poly(N-vinylacetamide) (repeat unit)	C_4H_7NO	46	even	2	polymer repeat unit
1-aminocyclopropanecarboxylic acid	$C_4H_7NO_2$	54	even	2	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
aceturic acid	$C_4H_7NO_3$	62	even	2	
aspartic acid	$C_4H_7NO_4$	70	even	2	
cyclobutane	C_4H_8	32	even	1	
asparagine	$C_4H_8N_2O_3$	70	even	2	
tetrahydrofuran	C_4H_8O	40	even	1	
ethyl acetate	$C_4H_8O_2$	48	even	1	
gamma-hydroxybutyric acid	$C_4H_8O_3$	56	even	1	
n-butylmercuric chloride	C_4H_9ClHg	130	even	–	
n-butyllithium	C_4H_9Li	36	even	–	
gamma-aminobutyric acid	$C_4H_9NO_2$	56	even	1	
threonine	$C_4H_9NO_3$	64	even	1	
n-butylsodium	C_4H_9Na	44	even	–	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
butyl alcohol	C_4H_9OH	42	even	0	
butane	C_4H_{10}	34	even	0	
2-methylpropane	C_4H_{10}	34	even	0	
1,2-butanediol	$C_4H_{10}O_2$	50	even	0	
1,3-butanediol	$C_4H_{10}O_2$	50	even	0	
1,4-butanediol	$C_4H_{10}O_2$	50	even	0	
2,3-butanediol	$C_4H_{10}O_2$	50	even	0	
tert-butyl hydroperoxide	$C_4H_{10}O_2$	50	even	0	
dimethoxyethane	$C_4H_{10}O_2$	50	even	0	
2-ethoxyethanol	$C_4H_{10}O_2$	50	even	0	
1-methoxy-2-propanol	$C_4H_{10}O_2$	50	even	0	
diethylene glycol	$C_4H_{10}O_3$	58	even	0	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
diethanolamine	$C_4H_{11}NO_2$	58	even	0	
2-bromo-5-nitropyridine	$C_5H_3BrN_2O_2$	98	even	5	
3,5-dibromopyridine	$C_5H_3Br_2N$	110	even	4	
2-chloro-5-nitropyridine	$C_5H_3ClN_2O_2$	80	even	5	
6-chloropurine	$C_5H_3ClN_4$	78	even	6	
niacin	C_5H_4NCOOH	64	even	5	
pyrazinoic acid	$C_5H_4N_2O_2$	64	even	5	
orotic acid	$C_5H_4N_2O_4$	80	even	5	
allopurinol	$C_5H_4N_4O$	70	even	6	
hypoxanthine	$C_5H_4N_4O$	70	even	6	
xanthine	$C_5H_4N_4O_2$	78	even	6	
mercaptopurine	$C_5H_4N_4S$	78	even	6	
cyclopentadienone	C_5H_4O	42	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
furfural	$C_5H_4O_2$	50	even	4	
thiophenecarboxylic acid	$C_5H_4O_2S$	66	even	4	
cyclopentadienyl anion	$C_5H_5^-$	36	even	–	
2-amino-5-bromopyridine	$C_5H_5BrN_2$	84	even	4	
2-amino-4-chloropyridine	$C_5H_5ClN_2$	66	even	4	
2-amino-5-chloropyridine	$C_5H_5ClN_2$	66	even	4	
4-amino-2-chloropyridine	$C_5H_5ClN_2$	66	even	4	
2-amino-5-iodopyridine	$C_5H_5IN_2$	102	even	4	
pyridine	C_5H_5N	42	even	4	
2-pyridone	C_5H_5NO	50	even	4	
3-pyridinol	C_5H_5NO	50	even	4	
pyrazinamide	$C_5H_5N_3O$	64	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
2-amino-nitropyridine	$C_5H_5N_3O_2$	72	even	5	
adenine	$C_5H_5N_5$	70	even	6	
guanine	$C_5H_5N_5O$	78	even	6	
3-pyridinylboronic acid	$C_5H_6BNO_2$	64	even	4	
1,2-diazepine	$C_5H_6N_2$	50	even	4	
1,3-diazepine	$C_5H_6N_2$	50	even	4	
1,4-diazepine	$C_5H_6N_2$	50	even	4	
1-vinylimidazole	$C_5H_6N_2$	50	even	4	
2-aminopyridine	$C_5H_6N_2$	50	even	4	
3-aminopyridine	$C_5H_6N_2$	50	even	4	
4-aminopyridine	$C_5H_6N_2$	50	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
glutaronitrile	$C_5H_6N_2$	50	even	4	
methylthiouracil	$C_5H_6N_2OS$	74	even	4	
thymine	$C_5H_6N_2O_2$	66	even	4	
cyclopentenone	C_5H_6O	44	even	3	
alpha-ketoglutaric acid	$C_5H_6O_5$	76	even	3	
3,4-diaminopyridine	$C_5H_7N_3$	58	even	4	
gamma-valerolactone	$C_5H_8O_2$	54	even	2	
3-dimethylaminoacrolein	C_5H_9NO	54	even	2	
allylglycine	$C_5H_9NO_2$	62	even	2	
proline	$C_5H_9NO_2$	62	even	2	
glutamic acid	$C_5H_9NO_4$	78	even	2	
cyclopentane	C_5H_{10}	40	even	1	
glutamine	$C_5H_{10}N_2O$	78	even	2	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
pivalic acid	$C_5H_{10}O_2$	56	even	1	
valeric acid	$C_5H_{10}O_2$	56	even	1	
3-methylbutanoic acid	$C_5H_{10}O_2$	56	even	1	
deoxyribose	$C_5H_{10}O_4$	72	even	1	
valine	$C_5H_{11}NO_2$	64	even	1	
methionine	$C_5H_{11}NO_2S$	80	even	1	
pentane	C_5H_{12}	42	even	0	
neopentyl glycol	$C_5H_{12}O_2$	58	even	0	
pentaerythritol	$C_5H_{12}O_4$	74	even	0	
xylitol	$C_5H_{12}O_5$	82	even	0	
N,N-diethylmethylamine	$C_5H_{13}N$	50	even	0	
pentafluorobenzoic acid	C_6F_5COOH	104	even	5	
2,6-dichloroquinone-4-chloroimide	$C_6H_2Cl_3NO$	104	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
2,4,6-tribromophenol	$C_6H_3Br_3O$	152	even	4	
2,4,6-trichlorophenol	$C_6H_3Cl_3O$	98	even	4	
5-bromonicotinic acid	$C_6H_4BrNO_2$	98	even	5	
2-chloronicotinic acid	$C_6H_4ClNO_2$	80	even	5	
4-chlorophenyl azide	$C_6H_4ClN_3$	78	even	6	
6-chloro-2-pyridinecarboxylic acid	$C_6H_4ClNO_2$	80	even	5	
6-chloronicotinic acid	$C_6H_4ClNO_2$	80	even	5	
tricyanoaminopropene	$C_6H_4N_4$	68	even	7	
ortho-benzoquinone	$C_6H_4O_2$	56	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
para-benzoquinone	$C_6H_4O_2$	56	even	5	
bromobenzene	C_6H_5Br	76	even	4	
benzaldehyde	C_6H_5CHO	56	even	5	
benzyl alcohol	$C_6H_5CH_2OH$	58	even	4	
chlorobenzene	C_6H_5Cl	58	even	4	
benzoyl chloride	C_6H_5COCl	72	even	5	
benzoate ion	$C_6H_5COO^-$	64	even	–	
benzoic acid	C_6H_5COOH	64	even	5	
fluorobenzene	C_6H_5F	50	even	4	
iodobenzene	C_6H_5I	94	even	4	
picolinic acid	$C_6H_5NO_2$	64	even	5	
4-nitrophenol	$C_6H_5NO_3$	72	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
6-hydroxynicotinic acid	$C_6H_5NO_3$	72	even	5	
phenol	C_6H_5OH	50	even	4	
citrate ion	$C_6H_5O_7^{3-}$	100	even	–	
citrazinic acid	$C_6H_5NO_4$	80	even	5	
tetraphenylgermane	$(C_6H_5)_4Ge$	196	even	–	
diphenyl ether	$(C_6H_5)_2O$	90	even	8	
triphenylamine	$(C_6H_5)_3N$	130	even	12	
triphenylphosphine	$(C_6H_5)_3P$	138	even	12	
benzene	C_6H_6	42	even	4	
4-chlorophenylboronic acid	$C_6H_6BClO_2$	80	even	4	
4-fluorophenylboronic acid	$C_6H_6BFO_2$	72	even	4	
2-chloromethylpyridine	C_6H_6ClN	66	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
4-iodoaniline	C_6H_6IN	102	even	4	
nicotinamide	$C_6H_6N_2O$	64	even	5	
6-aminonicotinic acid	$C_6H_6N_2O_2$	72	even	5	
2,2',2''-nitrilotriacetonitrile	$C_6H_6N_4$	70	even	6	
catechol	$C_6H_6O_2$	58	even	4	
hydroquinone	$C_6H_6O_2$	58	even	4	
resorcinol	$C_6H_6O_2$	58	even	4	
hydroxymethylfurfural	$C_6H_6O_3$	66	even	4	
phenylboronic acid	$C_6H_7BO_2$	64	even	4	
caesium ascorbate	$C_6H_7CsO_6$	146	even	–	
potassium ascorbate	$C_6H_7KO_6$	110	even	–	
potassium erythorbate	$C_6H_7KO_6$	110	even	–	
lithium ascorbate	$C_6H_7LiO_6$	94	even	–	
isoniazid	$C_6H_7N_3O$	72	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
sodium ascorbate	$C_6H_7NaO_6$	102	even	–	
rubidium ascorbate	$C_6H_7RbO_6$	128	even	–	
2-amino-3-methylpyridine	$C_6H_8N_2$	58	even	4	
2-amino-4-methylpyridine	$C_6H_8N_2$	58	even	4	
2-amino-5-methylpyridine	$C_6H_8N_2$	58	even	4	
2-amino-6-methylpyridine	$C_6H_8N_2$	58	even	4	
ethyl 2-aminothiazole-4-carboxylate (as printed)	$C_6H_8N_2O_2S$	90	even	4	
sulfanilamide	$C_6H_8N_2O_2S$	90	even	4	
citric acid	$C_6H_8O_7$	100	even	3	
histidine	$C_6H_9N_3O_2$	82	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
ethyl 5-amino-1H-pyrazole-4-carboxylate (as printed)	$C_6H_9N_3O_2$	82	even	4	
metronidazole	$C_6H_9N_3O_3$	90	even	4	
(2R)-2-methylpent-4-enoic acid	$C_6H_{10}O_2$	62	even	2	
4-acetylbutyric acid	$C_6H_{10}O_3$	70	even	2	
butyl glyoxylate	$C_6H_{10}O_3$	70	even	2	
ethyl acetoacetate	$C_6H_{10}O_3$	70	even	2	
2-hydroxypropyl acrylate	$C_6H_{10}O_3$	70	even	2	
pantolactone	$C_6H_{10}O_3$	70	even	2	
propyl pyruvate	$C_6H_{10}O_3$	70	even	2	
aceburic acid	$C_6H_{10}O_4$	78	even	2	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
adipic acid	$C_6H_{10}O_4$	78	even	2	
conduritol	$C_6H_{10}O_4$	78	even	2	
dianhydrohexitol	$C_6H_{10}O_4$	78	even	2	
ethylidene diacetate	$C_6H_{10}O_4$	78	even	2	
glucal	$C_6H_{10}O_4$	78	even	2	
cycloleucine	$C_6H_{11}NO_2$	70	even	2	
pipecolic acid	$C_6H_{11}NO_2$	70	even	2	
cyclohexane	C_6H_{12}	48	even	1	
streptolidine	$C_6H_{12}N_4O_3$	100	even	3	
4-mercapto-4-methyl-2-pentanone	$C_6H_{12}OS$	72	even	1	
4-hydroxy-4-methylpentanoic acid	$C_6H_{12}O_3$	72	even	1	
fructose	$C_6H_{12}O_6$	96	even	1	
glucose	$C_6H_{12}O_6$	96	even	1	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
N-ethylmorpholine	$C_6H_{13}NO$	64	even	1	
aminocaproic acid	$C_6H_{13}NO_2$	72	even	1	
isoleucine	$C_6H_{13}NO_2$	72	even	1	
leucine	$C_6H_{13}NO_2$	72	even	1	
hexane	C_6H_{14}	50	even	0	
lysine	$C_6H_{14}N_2O_2$	80	even	1	
N-methylornithine	$C_6H_{14}N_2O_2$	80	even	1	
arginine	$C_6H_{14}N_4O_2$	94	even	2	
1,6-hexanediol	$C_6H_{14}O_2$	66	even	0	
dipropylene glycol	$C_6H_{14}O_3$	74	even	0	
trimethylolpropane	$C_6H_{14}O_3$	74	even	0	
triethylene glycol	$C_6H_{14}O_4$	82	even	0	
triethanolamine	$C_6H_{15}NO_3$	82	even	0	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
2-oxohistidine	$C_6H_7N_3O_3$	88	even	5	
tetracyanoethylene	C_6N_4	64	even	9	
2-chloro-6-fluorobenzaldehyde	C_7H_4ClFO	80	even	5	
trinitrotoluene	$C_7H_5N_3O_6$	116	even	7	
3-bromobenzaldehyde	C_7H_5BrO	90	even	5	
2,4,6-tribromoanisole	$C_7H_5Br_3O$	160	even	4	
chlorthiamid	$C_7H_5Cl_2NS$	104	even	5	
2,4,6-trichloroanisole	$C_7H_5Cl_3O$	106	even	4	
2,4,6-trifluoroanisole	$C_7H_5F_3O$	82	even	4	
2-fluorobenzoic acid	$C_7H_5FO_2$	72	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
3-fluorobenzoic acid	$C_7H_5FO_2$	72	even	5	
4-fluorobenzoic acid	$C_7H_5FO_2$	72	even	5	
quinolinic acid	$C_7H_5NO_4$	86	even	6	
dipicolinic acid	$C_7H_5NO_4$	86	even	6	
2-mercaptobenzothiazole	$C_7H_5NS_2$	86	even	6	
7-nitroindazole	$C_7H_5N_3O_2$	84	even	7	
2-chloro-6-fluorotoluene	C_7H_6ClF	74	even	4	
7-azaindole	$C_7H_6N_2$	62	even	6	
benzimidazole	$C_7H_6N_2$	62	even	6	
tropone	C_7H_6O	56	even	5	
4-hydroxybenzaldehyde	$C_7H_6O_2$	64	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
salicylic acid	$C_7H_6O_3$	72	even	5	
4-hydroxybenzoic acid	$C_7H_6O_3$	72	even	5	
protocatechuic acid	$C_7H_6O_4$	80	even	5	
2,3-dihydroxybenzoic acid	$C_7H_6O_4$	80	even	5	
gallic acid	$C_7H_6O_5$	88	even	5	
4-carboxyphenylboronic acid	$C_7H_7BO_4$	86	even	5	
4-aminobenzoic acid	$C_7H_7NO_2$	72	even	5	
homarine	$C_7H_7NO_2$	72	even	5	
mesalazine	$C_7H_7NO_3$	80	even	5	
benomyl metabolite	$C_7H_7N_3$	70	even	6	
toluene	C_7H_8	50	even	4	
hydrochlorothiazide	$C_7H_8ClN_3O_4S_2$	152	even	5	
theophylline	$C_7H_8N_4O_2$	94	even	6	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
theobromine	$C_7H_8N_4O_2$	94	even	6	
4-methylphenylboronic acid	$C_7H_9BO_2$	72	even	4	
4-boronoanisole	$C_7H_9BO_3$	80	even	4	
4-dimethylaminopyridine	$C_7H_{10}N_2$	66	even	4	
N-acetylglutamic acid	$C_7H_{11}NO_5$	100	even	3	
diethyl malonate	$C_7H_{12}O_4$	86	even	2	
aceglutamide	$C_7H_{12}N_2O_4$	100	even	3	
n-butyl lactate	$C_7H_{14}O_3$	80	even	1	
bornesitol	$C_7H_{14}O_6$	104	even	1	
methyl-alpha-D-galactoside	$C_7H_{14}O_6$	104	even	1	
heptane	C_7H_{16}	58	even	0	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
Togni reagent II	$C_8H_4F_3IO_2$	148	even	5	
riluzole	$C_8H_5F_3N_2OS$	118	even	6	
isatin	$C_8H_5NO_2$	76	even	7	
5-bromoindole	C_8H_6BrN	96	even	6	
6-bromoindole	C_8H_6BrN	96	even	6	
4-chloroindole	C_8H_6ClN	78	even	6	
2,4-dichlorophenoxyacetic acid	$C_8H_6Cl_2O_3$	112	even	5	
4-quinazolinol	$C_8H_6N_2O$	76	even	7	
indazolium-3-carboxylate	$C_8H_6N_2O_2$	84	even	7	
2-chlorostyrene	C_8H_7Cl	72	even	5	
indole	C_8H_7N	62	even	6	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
indol-4-ol	C_8H_7NO	70	even	6	
oxindole	C_8H_7NO	70	even	6	
5-hydroxyindole	C_8H_7NO	70	even	6	
cubane	C_8H_8	56	even	5	
luminol	$C_8H_7N_3O_2$	92	even	7	
2-amino-6-methoxybenzothiazole	$C_8H_8N_2OS$	94	even	6	
4-hydroxyphenylacetic acid	$C_8H_8O_3$	80	even	5	
isovanillin	$C_8H_8O_3$	80	even	5	
vanillic acid	$C_8H_8O_4$	88	even	5	
acetaminophen	$C_8H_9NO_2$	80	even	5	
aminomethylbenzoic acid	$C_8H_9NO_2$	80	even	5	
hydroxydanaidal	$C_8H_9NO_2$	80	even	5	
methyl anthranilate	$C_8H_9NO_2$	80	even	5	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
4-iodo-N,N-dimethylaniline	$C_8H_{10}IN$	118	even	4	
caffeine	$C_8H_{10}N_4O_2$	102	even	6	
tyramine	$C_8H_{11}NO$	74	even	4	
aciclovir	$C_8H_{11}N_5O_3$	118	even	6	
1,2,3-trimethylcyclopentane	C_8H_{16}	64	even	1	
cyclohexanedimethanol	$C_8H_{16}O_2$	80	even	1	
pinpollitol	$C_8H_{16}O_6$	112	even	1	
viscumitol	$C_8H_{16}O_6$	112	even	1	
eleutheroside C	$C_8H_{16}O_6$	112	even	1	
octane	C_8H_{18}	66	even	0	
4-bromoisoquinoline	C_9H_6BrN	102	even	7	
5-cyanoindole	$C_9H_6N_2$	74	even	8	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
umbelliferone	$C_9H_6O_3$	84	even	7	
thiochromone	C_9H_6OS	84	even	7	
8-hydroxyquinoline	C_9H_7NO	76	even	7	
indole-3-carboxaldehyde	C_9H_7NO	76	even	7	
indole-2-carboxylic acid	$C_9H_7NO_2$	84	even	7	
indole-3-carboxylic acid	$C_9H_7NO_2$	84	even	7	
5-aminoisoquinoline	$C_9H_8N_2$	76	even	7	
5-aminoquinoline	$C_9H_8N_2$	76	even	7	
6-aminoquinoline	$C_9H_8N_2$	76	even	7	
8-aminoquinoline	$C_9H_8N_2$	76	even	7	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
cinnamic acid	$C_9H_8O_2$	78	even	6	
o-coumaric acid	$C_9H_8O_3$	86	even	6	
m-coumaric acid	$C_9H_8O_3$	86	even	6	
p-coumaric acid	$C_9H_8O_3$	86	even	6	
aspirin	$C_9H_8O_4$	94	even	6	
caffeic acid	$C_9H_8O_4$	94	even	6	
methylketol	C_9H_9N	70	even	6	
skatole	C_9H_9N	70	even	6	
4-methoxyindole	C_9H_9NO	78	even	6	
5-methoxyindole	C_9H_9NO	78	even	6	
6-methoxyindole	C_9H_9NO	78	even	6	
indole-3-carbinol	C_9H_9NO	78	even	6	
hippuric acid	$C_9H_9NO_3$	94	even	6	
stizolobic acid	$C_9H_9NO_6$	118	even	6	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
chavicol	$C_9H_{10}O$	72	even	5	
paeonol	$C_9H_{10}O_3$	88	even	5	
L-phenylalanine	$C_9H_{11}NO_2$	88	even	5	
cinnamyl alcohol	$C_9H_{10}O$	72	even	5	
tyrosine	$C_9H_{11}NO_3$	96	even	5	
L-DOPA	$C_9H_{11}NO_4$	104	even	5	
4-ipomeanol	$C_9H_{12}O_3$	90	even	4	
S2242	$C_9H_{13}N_5O_3$	126	even	6	
boonein	$C_9H_{14}O_3$	92	even	3	
gabapentin	$C_9H_{17}NO_2$	94	even	2	
1-boc-piperazine	$C_9H_{18}N_2O_2$	102	even	2	
nonane	C_9H_{20}	74	even	0	
mono-BOC-cystamine	$C_9H_{20}N_2O_2S_2$	136	even	1	
N,N’-di-n-butylthiourea	$C_9H_{20}N_2S$	104	even	1	
pentabromopseudilin	$C_{10}H_4Br_5NO$	254	even	7	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
quinaldic acid	$C_{10}H_7NO_2$	90	even	8	
6-hydroxykynurenic acid	$C_{10}H_7NO_4$	106	even	8	
tiabendazole	$C_{10}H_7N_3S$	104	even	9	
azulene	$C_{10}H_8$	68	even	7	
naphthalene	$C_{10}H_8$	68	even	7	
hymecromone	$C_{10}H_8O_3$	92	even	7	
indole-3-acetic acid	$C_{10}H_9NO_2$	92	even	7	
kinetin	$C_{10}H_9N_5O$	112	even	9	
5-methoxyindole-3-carboxaldehyde	$C_{10}H_9NO_2$	92	even	7	
basketene	$C_{10}H_{10}$	70	even	6	
edaravone	$C_{10}H_{10}N_2O$	92	even	7	
suosan	$C_{10}H_{10}N_3NaO_5$	142	even	–	
safrole	$C_{10}H_{10}O_2$	86	even	6	
ferulic acid	$C_{10}H_{10}O_4$	102	even	6	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
sulfamethoxazole	$C_{10}H_{11}N_3O_3S$	132	even	7	
tryptamine	$C_{10}H_{12}N_2$	86	even	6	
anethole	$C_{10}H_{12}O$	80	even	5	
estragole	$C_{10}H_{12}O$	80	even	5	
hinokitiol	$C_{10}H_{12}O_2$	88	even	5	
eugenol	$C_{10}H_{12}O_2$	88	even	5	
isoeugenol	$C_{10}H_{12}O_2$	88	even	5	
pseudoisoeugenol	$C_{10}H_{12}O_2$	88	even	5	
coniferyl alcohol	$C_{10}H_{12}O_3$	96	even	5	
adenosine	$C_{10}H_{13}N_5O_4$	140	even	7	
N-tert-butylbenzenesulfinimidoyl chloride	$C_{10}H_{14}ClNS$	114	even	4	
nicotine	$C_{10}H_{14}N_2$	88	even	5	
titanium bis(acetylacetonate)dichloride	$C_{10}H_{14}Cl_2O_4Ti$	162	even	–	
carvone	$C_{10}H_{14}O$	82	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
1-bromoadamantane	$C_{10}H_{15}Br$	110	even	3	
ephedrine	$C_{10}H_{15}ON$	90	even	4	
limonene	$C_{10}H_{16}$	76	even	3	
camphor	$C_{10}H_{16}O$	84	even	3	
boc-4-piperidone	$C_{10}H_{17}NO_3$	108	even	3	
fructose-asparagine	$C_{10}H_{18}N_2O_8$	156	even	3	
biotin hydrazide	$C_{10}H_{18}N_4O_2S$	138	even	4	
1-boc-4-piperidinol	$C_{10}H_{19}NO_3$	110	even	2	
boc-4-aminopiperidine	$C_{10}H_{20}N_2O_2$	110	even	2	
paramenthane hydroperoxide	$C_{10}H_{20}O_2$	96	even	1	
decane	$C_{10}H_{22}$	82	even	0	
menadione	$C_{11}H_8O_2$	90	even	8	
beta-naphthol methyl ether	$C_{11}H_{10}O$	84	even	7	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
3-indolepropionic acid	$C_{11}H_{11}NO_2$	100	even	7	
tryptophan	$C_{11}H_{12}N_2O_2$	108	even	7	
myristicin	$C_{11}H_{12}O_3$	102	even	6	
caramboxin	$C_{11}H_{13}NO_6$	134	even	6	
5-methoxytryptamine	$C_{11}H_{14}N_2O$	102	even	6	
methyl eugenol	$C_{11}H_{14}O_2$	96	even	5	
methyl isoeugenol	$C_{11}H_{14}O_2$	96	even	5	
jasmolone	$C_{11}H_{16}O_2$	98	even	4	
boc-isonipecotic acid	$C_{11}H_{19}NO_4$	124	even	3	
L-arginine L-pyroglutamate	$C_{11}H_{21}N_5O_5$	162	even	4	
undecane	$C_{11}H_{24}$	90	even	0	
macromomycin B (as printed)	$C_{12}H_{11}NO_5$	130	even	8	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
2,2',3,3',4,4'-hexachlorobiphenyl	$C_{12}H_4Cl_6$	178	even	8	
tetracyanoquinodimethane	$C_{12}H_4N_4$	104	even	13	
methoxsalen	$C_{12}H_8O_4$	112	even	9	
biphenyl	$C_{12}H_{10}$	82	even	8	
furosemide (as printed)	$C_{12}H_{10}ClN_2O_5S$	169	odd	8.5	source formula; $C_{12}H_{11}ClN_2O_5S$
furonazide	$C_{12}H_{11}N_3O_2$	120	even	9	
6-benzylaminopurine	$C_{12}H_{11}N_5$	118	even	10	
triamterene	$C_{12}H_{11}N_7$	132	even	11	
indole-3-butyric acid	$C_{12}H_{13}NO_2$	108	even	7	
calcium alginate (repeat unit)	$C_{12}H_{14}CaO_{12}$	202	even	–	polymer repeat unit
apiole	$C_{12}H_{14}O_4$	118	even	6	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
dillapiole	$C_{12}H_{14}O_4$	118	even	6	
1-benzyl-4-piperidone	$C_{12}H_{15}NO$	102	even	6	
N,N-dimethyltryptamine	$C_{12}H_{16}N_2$	102	even	6	
asarone	$C_{12}H_{16}O_3$	112	even	5	
elemicin	$C_{12}H_{16}O_3$	112	even	5	
isoelemicin	$C_{12}H_{16}O_3$	112	even	5	
oudenone	$C_{12}H_{16}O_3$	112	even	5	
2,4,5-trimethoxypropiophenone	$C_{12}H_{16}O_4$	120	even	5	
arbutin	$C_{12}H_{16}O_7$	144	even	5	
thiamine nitrate	$C_{12}H_{17}N_5O_4S$	172	even	7	
E1210	$C_{12}H_{18}N_4O_2$	134	even	6	
propofol	$C_{12}H_{18}O$	98	even	4	
allixin	$C_{12}H_{18}O_4$	122	even	4	
D-fructose-L-histidine	$C_{12}H_{19}N_3O_7$	168	even	5	
aspartylglucosamine	$C_{12}H_{21}N_3O_8$	178	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
1,1'-dihydroxydicyclohexyl peroxide	$C_{12}H_{22}O_4$	126	even	2	
maltose	$C_{12}H_{22}O_{11}$	182	even	2	
sucrose	$C_{12}H_{22}O_{11}$	182	even	2	
stenusin	$C_{12}H_{25}N$	104	even	1	
dodecane	$C_{12}H_{26}$	98	even	0	
tetracyclopropylmethane	$C_{13}H_{20}$	98	even	4	
benzophenone	$C_{13}H_{10}O$	96	even	9	
fluconazole	$C_{13}H_{12}F_2N_6O$	158	even	10	
beta-ionone (as printed)	$C_{13}H_{12}O$	98	even	8	
monobenzone	$C_{13}H_{12}O_2$	106	even	8	
harmaline	$C_{13}H_{14}N_2O$	114	even	8	
melatonin	$C_{13}H_{16}N_2O_2$	124	even	7	
ibuprofen	$C_{13}H_{18}O_2$	112	even	5	
tridecane	$C_{13}H_{28}$	106	even	0	
anthracene	$C_{14}H_{10}$	94	even	10	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
phenanthrene	$C_{14}H_{10}$	94	even	10	
benzoyl peroxide (as printed)	$C_{14}H_{10}O_{14}$	206	even	10	source formula; $C_{14}H_{10}O_4$ (not caught)
RI-1	$C_{14}H_{11}Cl_3N_2O_3$	184	even	9	
isooncodine	$C_{14}H_{11}NO_3$	126	even	10	
meso-stilbene dibromide	$C_{14}H_{12}Br_2$	166	even	8	
resveratrol	$C_{14}H_{12}O_3$	120	even	9	
flufenacet	$C_{14}H_{13}F_4N_3O_2S$	186	even	8	
enilconazole	$C_{14}H_{14}Cl_2N_2O$	154	even	8	
SCH 900271	$C_{14}H_{16}N_2O_4$	146	even	8	
TDBzcholine	$C_{14}H_{17}F_3N_3O_2$	165	odd	6.5	cation; charge missing in source
aspartame	$C_{14}H_{18}N_2O_5$	156	even	7	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
trimethoprim	$C_{14}H_{18}N_4O_3$	154	even	8	
bis(2-methoxyethyl) phthalate	$C_{14}H_{18}O_6$	150	even	6	
integrasone	$C_{14}H_{20}O_5$	144	even	5	
tetradecane	$C_{14}H_{30}$	114	even	0	
daidzein	$C_{15}H_{10}O_4$	132	even	11	
apigenin	$C_{15}H_{10}O_5$	140	even	11	
emodin	$C_{15}H_{10}O_5$	140	even	11	
genistein	$C_{15}H_{10}O_5$	140	even	11	
luteolin	$C_{15}H_{10}O_6$	148	even	11	
quercetin	$C_{15}H_{10}O_7$	156	even	11	
carbamazepine	$C_{15}H_{12}N_2O$	124	even	11	
phenytoin	$C_{15}H_{12}N_2O_2$	132	even	11	
darienine	$C_{15}H_{13}NO_4$	142	even	10	
curzerenone	$C_{15}H_{18}O_2$	124	even	7	
arglabin	$C_{15}H_{18}O_3$	132	even	7	
nectaryl	$C_{15}H_{24}O$	122	even	4	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
pentadecane	$C_{15}H_{32}$	122	even	0	
virstatin	$C_{16}H_{13}NO_4$	148	even	11	
ketoprofen	$C_{16}H_{14}O_3$	134	even	10	
norscopolamine	$C_{16}H_{19}NO_4$	154	even	8	
peyonine	$C_{16}H_{19}NO_5$	162	even	8	
LY3372689	$C_{16}H_{22}FN_5O_3S$	202	even	8	
zinc acexamate	$C_{16}H_{28}N_2O_6Zn$	216	even	–	
biotin PEG2 amine	$C_{16}H_{30}N_4O_4S$	202	even	4	
hexadecane	$C_{16}H_{34}$	130	even	0	
alprazolam	$C_{17}H_{13}ClN_4$	160	even	13	
celecoxib	$C_{17}H_{14}F_3N_3O_2S$	196	even	11	
olivacine	$C_{17}H_{14}N_2$	130	even	12	
5-methyl-7-methoxyisoflavone	$C_{17}H_{14}O_3$	140	even	11	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
calmagite	$C_{17}H_{14}N_2O_5S$	186	even	12	
noroliveroline	$C_{17}H_{15}NO_3$	148	even	11	
TSQ	$C_{17}H_{16}N_2O_3S$	172	even	11	
nifedipine	$C_{17}H_{18}N_2O_6$	182	even	10	
omeprazole	$C_{17}H_{19}N_3O_3S$	182	even	10	
cocaine	$C_{17}H_{21}NO_4$	162	even	8	
cicutoxin	$C_{17}H_{22}O_2$	140	even	7	
oenanthotoxin	$C_{17}H_{22}O_2$	140	even	7	
falcarinol	$C_{17}H_{24}O$	134	even	6	
eleutheroside B	$C_{17}H_{24}O_9$	198	even	6	
glyceryl octyl ascorbic acid	$C_{17}H_{30}O_8$	196	even	3	
heptadecane	$C_{17}H_{36}$	138	even	0	
boscalid	$C_{18}H_{12}Cl_2N_2O$	176	even	13	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
INH1	$C_{18}H_{16}N_2OS$	162	even	12	
oliveroline	$C_{18}H_{17}NO_3$	156	even	11	
xylopine	$C_{18}H_{17}NO_3$	156	even	11	
clovamide	$C_{18}H_{17}NO_7$	188	even	11	
estrone	$C_{18}H_{22}O_2$	146	even	8	
tazopsine	$C_{18}H_{23}NO_6$	186	even	8	
estradiol	$C_{18}H_{24}O_2$	148	even	7	
estriol	$C_{18}H_{24}O_3$	156	even	7	
estetrol	$C_{18}H_{24}O_4$	164	even	7	
capsaicin	$C_{18}H_{27}NO_3$	166	even	6	
linoleic acid	$C_{18}H_{32}O_2$	156	even	3	
octadecane	$C_{18}H_{38}$	146	even	0	
bromopyrogallol red	$C_{19}H_{10}Br_2O_9S$	282	even	14	
6-formylindolo(3,2-b)carbazole	$C_{19}H_{12}N_2O$	148	even	15	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
C286	$C_{19}H_{14}N_2O_4$	174	even	14	
landomycinone	$C_{19}H_{14}O_6$	176	even	13	
coumachlor	$C_{19}H_{15}ClO_4$	178	even	12	
indometacin	$C_{19}H_{16}ClNO_4$	186	even	12	
eburnamenine	$C_{19}H_{22}N_2$	150	even	10	
normacusine B	$C_{19}H_{22}N_2O$	158	even	10	
eburnamine	$C_{19}H_{24}N_2O$	160	even	9	
androstenedione	$C_{19}H_{26}O_2$	156	even	7	
dehydroepiandrosterone	$C_{19}H_{28}O_2$	158	even	6	
testosterone	$C_{19}H_{28}O_2$	158	even	6	
androstenediol	$C_{19}H_{30}O_2$	160	even	5	
dihydrotestosterone	$C_{19}H_{30}O_2$	160	even	5	
nonadecane	$C_{19}H_{40}$	154	even	0	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
sibiricine	$C_{20}H_{17}NO_6$	192	even	13	
N,N-dibenzylaniline	$C_{20}H_{19}N$	146	even	12	
tetrakis(pyridine)silver(II) peroxydisulfate	$C_{20}H_{20}N_4AgS_2O_8$	311	odd	–	open shell
kopsanone	$C_{20}H_{22}N_2O$	164	even	11	
pleiocarpamine	$C_{20}H_{22}N_2O_2$	172	even	11	
saudin	$C_{20}H_{22}O_7$	198	even	10	
BX-912	$C_{20}H_{23}BrN_8O$	242	even	13	
thebacon	$C_{20}H_{23}NO_4$	182	even	10	
quinine	$C_{20}H_{24}O_2N_2$	174	even	10	
diphepanol	$C_{20}H_{25}NO$	160	even	9	
crotogoudin	$C_{20}H_{26}O_3$	170	even	8	
amygdalin	$C_{20}H_{27}NO_{11}$	242	even	8	
tretinoin	$C_{20}H_{28}O_2$	164	even	7	

Name	Formula	Electrons	Parity	$R + \Pi$	Note
neotripterifordin	$C_{20}H_{30}O_3$	174	even	6	
prostacyclin	$C_{20}H_{32}O_5$	192	even	5	
prostaglandin E2	$C_{20}H_{32}O_5$	192	even	5	
dinoprost	$C_{20}H_{34}O_5$	194	even	4	
eicosane	$C_{20}H_{42}$	162	even	0	
AMG 319	$C_{21}H_{16}FN_7$	200	even	17	
avutometinib	$C_{21}H_{18}FN_5O_5S$	244	even	15	
setanaxib	$C_{21}H_{19}ClN_4O_2$	206	even	14	
curcumin	$C_{21}H_{20}O_6$	194	even	12	

Appendix D — Verdicts of the Judges

Independent judges worked under the Respondent–Judge protocol on 6 November 2026. Each wrote its own code and recorded its own test ranges before reading the text, read every proof, re-derived each step and searched the literature. No judge read the respondent's code. The main results were computed a third time with new code (G8, Appendix A.11–A.14 and B).

Family	Items	Verified	With fixes	Gap	Refuted	Known
Ground (Ch. 1–8)	31	12	17	2	0	14
Physics (Ch. 9–15, 25.1–25.2, 26)	40	17	20	3	0	10
Chemistry (Ch. 16–21, 25.3, App. C)	45	24	14	2	0	9
Climate (Ch. 22–24, 25.4)	38	19	14	0	1	3
Maxwell quaternion form (25.1, second round)	17	6	7	0	0	3

Family	Items	Verified	With fixes	Gap	Refuted	Known
Windows and gravity (25.5–25.6, A.15–A.16)	24	12	10	1	1	3
Axioms N6–N7, bridge, deflection, ratios (1.3, 1.5, 8.3, 11.1, 13.6, 14.1, 25.7–25.9, A.17–A.19)	37	23	12	1	1	3
External influences on the climate (23.8)	32	17	12	2	1	3

Family	Items	Verified	With fixes	Gap	Refuted	Known
Proton reading, agenda, dictionary, objections (15.5–15.7, 28, App. H, I, A.21)	10	3	7	3	0	2

Notes. “Known” is an added marker for ground, physics and chemistry, and a separate verdict for climate. Physics: one item (Foundations T21) lies outside the family and was not judged. Chemistry: five items are correspondences, confirmed as correctly labelled. Climate: the refutation concerns wording only; one footnote was not checked. Maxwell (second round): four items are correspondences or citations confirmed as labelled; the main fixes were three equation letters in the table of Article 619 and the symmetric second difference needed for the wave equation. Windows and gravity: the refutation concerns wording only (Maxwell compared gravity with two like magnetic poles, not with electrostatic induction); the gap was the undefined sign in the product rule of H-Q1′, now given explicitly; the judge added that the split into positive field energy and a coupling term is known (Ohanian; Lynden-Bell and Katz; Bengtsson and Eklund 2022) and that point 5 of B14 is computed under T23, not proven. Third edition round: all numbers verified; the gap was the justification of H-S, which as first worded described Nordström’s scaling; H-S is now stated as input equivalent to γ_PPN = 1. The refutation concerned the wording “can only mean” in 14.1, contradicted by B16. Gravity Probe B was moved from support to constraint of the scalar reading. Section 23.8: the refutation concerned the wording “the Milankovitch cycles are produced by the planets” (the axial part also comes from the Sun–Moon torque); the gaps were the missing basis and status of the tide table, now recomputed at closest approach, and a single literature value for the 65° N range. Chapters 15, 28 and Appendices H and I: no refutation; the gaps were the missing P2 in the list of predictions, items of Chapters 24 and 26 missing from the agenda, and statuses in H and I stronger than in the

register. All were corrected. Positive rewording (opening “What Is Different” and the “In short” blocks): a judge checked every short statement against the register and found 21 statements stronger than their basis, 12 wrong tags, 9 grammatical faults and 5 actor verbs; all were corrected before release. Part 0 (the short book): all numbers verified; two numbers corrected (gravity is about 10^{36} times weaker, not 10^{37}; depth 12 is not the closest miss of the ladders); 28 plain statements stronger than their basis rewritten as readings or with their assumption named.

Status of the fixes. All fixes listed by the judges were applied in this edition. The one refuted claim was the wording “the logarithm is now derived” in 25.4; the derivation uses spectroscopic inputs only, and the text now says so.

Gaps after the fixes.

Gap	Where	State
Trit rule undefined at the ends of the strand and ambiguous when the first passage leaves the way it came in	2.3	open (belongs to IX.5)
Lever not defined	8.2	closed: definition and proof added
P4 has no operational criterion or time horizon	13.5	open
$\beta = \alpha/4\pi$ in P1 not derived	14.5	marked as input
Appendix sections A.11–A.14 missing	25	closed: added
Sign rule of H-Q1′ undefined	25.5	closed: rule with $\sigma(u)\sigma(v)$ given

Gap	Where	State
Coverage of the Wikipedia reading and CAS figures not checked by the judge	19.6	checked by the respondent against two sources (Chapter 19.6)

Count differences reported. The judge for chemistry reproduced every count of Chapter 19.6 from the same table, and showed that the charge-closure split depends on the table of oxidation states (Chapter 19.6). The judge for the ground chapters found that the closure depths are records in ratio, not in absolute difference, and that the Eisenstein share oscillates; both are now in the text.

Attestation. Under the protocol the one human act is the attestation of the result by the author. This edition awaits that attestation.

Appendix E — Glossary of Terms

Term	Meaning in this book	First use
Address	The unique balanced-ternary word of an integer	Ch. 5
Band	The set of levels of a closed ring as its size grows without bound	Ch. 25.3
Carry	The part of a sum that passes to the next scale	Ch. 2
Closure	A window whose sum leaves no residue at its own scale	Ch. 3
Closure depth	A depth at which powers of 3 come closer to a power of 2 than at any smaller depth	Ch. 6
Comma	The rest $3^{12}/2^{19}$ that never vanishes	Ch. 6
Read	A declared reading of a known result in the language of the net	How to Read
Distinction	The first act: a mark that splits a space	Ch. 1
Eigenform	A form that reproduces itself under an operation	Ch. 1
Input	A result taken from outside the theory and named as such	Ch. 27

Term	Meaning in this book	First use
Known	A result already in the literature, with source	Ch. 27
Ladder	The sequence of scales $2^a 3^b$	Ch. 6
Lever	The coupling γ of a count	Ch. 8
Loop	A return of the strand to a place it has been	Ch. 1
Meeting	The closure $x, -x$ of length 2, with carry 0	Ch. 4
Node	A place visited at least twice	Ch. 1
Open	No chain yet connects the axioms to the result	How to Read
Proven	Follows by proof; hypotheses and inputs named	How to Read
Refuted	Contradicted by an independently re-checked counterexample	Ch. 27
Ring	The closure x, x, x of length 3, with carry ± 1	Ch. 4
Seam	The joint between two closed windows	Ch. 4
Standing	The closure 0 of length 1	Ch. 4
State function	A response that depends on the state of the net (N4)	Ch. 1, 8

Term	Meaning in this book	First use
Light location	The place on the strand where light is; it moves one step per tick (N6)	Ch. 1.5, 25.8
Ratio	Every measurable quantity is a ratio of counts; length and time are references (N7)	Ch. 1.5, 11
Rate function	The Legendre transform of the cumulant generating function of a count (Cramér: the rate of the mean of independent copies); the energy of the net under H-R	Ch. 25.7
Strand	The one map $\sigma : I \to P$	Ch. 1
Tension	What does not close and passes on (N2)	Ch. 1
Trit	A digit $-1, 0, +1$ of balanced ternary	Ch. 2
Window	Three consecutive trits	Ch. 3

Appendix F — Constants and Inputs

Quantity	Value	Source	Status in this book
Speed of light c	299,792,458 m s^{-1}	SI definition	conversion (N7); one step per tick in the net (N6)
Planck constant h	$6.62607015 \times 10^{-34}$ J s	SI definition	conversion (N7)
Boltzmann constant k	1.380649×10^{-23} J K^{-1}	SI definition	input
Elementary charge e	$1.602176634 \times 10^{-19}$ C	SI definition	input
Rydberg constant R_∞	10,973,731.56816 0 m^{-1}	CODATA 2018	input
m_p/m_e	1836.15267343	CODATA 2018	input; open (O3)
Fine-structure constant α	0.0072973525693	CODATA 2018	input; open (O7)
$GM_\odot$	$1.32712440018 \times 10^{20}$ m^3 s^{-2}	IAU	input
Hubble constant H_0	67.4 / 70 / 73 km s^{-1} Mpc^{-1}	Planck 2018 / reference / SH0ES	input; open (O8)
Acceleration threshold	1.2×10^{-10} m s^{-2}	SPARC	input
Solar irradiance S	1,361 W m^{-2}	Kopp and Lean 2011	input
Albedo A	0.30	Trenberth et al. 2009	input
CO_2 1750 / 2024	278 / 423.9 ppm	IPCC TAR / WMO	input

Quantity	Value	Source	Status in this book
CO_2 coefficient	5.35 W m^{-2}	Myhre et al. 1998	input; B12 gives 6.9–7.8 (idealised)
Effective forcing, doubling	3.93 W m^{-2}	IPCC AR6	input
Climate sensitivity	3 °C (2.5–4)	IPCC AR6	input
Return probability P_3	0.3405373	Watson 1939	computed (Watson's integral; not a measurement)
Stiffness $\overline{g}$	1.2771 (units of the count)	Theorem B15	proven under H-R and T24

Appendix G — Register of Theorems

No.	Statement in short	Chapter	Status
Foundations T1	Trinity as register: digit and carry	2	proven
Foundations T2	Window of three	3	proven
Foundations T3–T4	9 of 27 windows close; all equal or all different	3	proven
Foundations T6	Closure probability	3	proven
Foundations T7	Standing, meeting, ring	4	proven
Foundations T7.1	Carry of a closure	4	proven
Foundations T8	Nine words close everywhere ($n \geq 3$)	4	proven
Foundations T9–T10	Fixed rings of the rewrite	4	proven
Foundations T11	Seam rule	4	proven
Foundations T12	Unique balanced-ternary address	5	proven; known
Foundations T13	Necklace count	5	proven; known
Foundations T14	Digit map in $\mathbb{Z}[\omega]$	5	proven (orbits); computed (shares)
Foundations T15	Ladder $2^a 3^b$	6	proven under hypothesis (equal blocks)
Foundations T16	$2^n \neq 3^k$	6	proven; known
Foundations T17	Closure depths	6	proven; known

No.	Statement in short	Chapter	Status
Foundations T18	Comma	6	proven; known
Foundations T19	Trefoil is the first knot	7	proven under hypothesis (embedding); known
Foundations T20	Jones polynomial; chirality	7	proven; known
Foundations T21	Return after 4π	7	proven under the quaternion hypothesis; known
Foundations T22	Hopf charge conserved	7	proven under hypotheses; known
Foundations T23	Stiffness as state function	8	proven under the stated energy density
Foundations T24	Lever of a free path	8	proven under hypothesis (free walk)
Physics T1	Nilpotence is the mass shell	9	proven (identity); known
Physics T2–T4	Quaternion identities; ring measure	10	proven
Physics T5	Dimensional bridge	11	proven (map); input (reading)
Physics T6	Loss has an address	12	known (de Groot–Mazur)

No.	Statement in short	Chapter	Status
B1	Shell capacity $2n^2$	16	proven under input
B2	Period lengths	17	proven under input (Madelung)
B3	Bond parity	18	proven; known
B4	Rings plus extra bond orders	18	proven under the valence hypothesis; known
B5	Two mirror forms	18	proven under input (tetrahedron)
B6	Hess's law	20	proven under input
B7	Electron parity	19	proven
B8	Charge closure	19	proven under input (oxidation-state table); table-dependent
B9	Field from closure (Maxwell's quaternion form)	25	proven under H-Q1, H-Q2; known
B10	Mass as reversal (1+1)	25	proven under H-D1; known
B11	Ring closure; 4n+2; band	25	proven under input; known
B12	Logarithmic forcing	25	proven under H1–H4; known

No.	Statement in short	Chapter	Status
B13	Windows carry Hamilton's axes and signs, not the product	25	proven (exhaustive); H-Q1 reduced to H-Q1′, open
B14	Like sources attract in a stiff net; $E_{\min} = -W$	25	points 1–4 proven under H-G1, known (Yukawa; Bengtsson–Eklund); point 5 computed under T23; conditions for $1/r$, sign of mass and light open
B15	Lever = coupling; $\overline{g} = 1/\kappa_2$	25	proven under H-R and T24; known (rate-function derivatives)
B16	Light deflection by refraction, $4GM/c^2b$	25	proven under N6, H-S (input, equivalent to $\gamma_{\mathrm{PPN}} = 1$) and Newtonian potential (input); known

Appendix H — Dictionary: Physics and the Net

This appendix gives, for each term of physics and chemistry used in this book, the term of the net and the status of the link. It is meant for physicists, chemists and language models trained on the standard literature. “Derived” means proven under the hypotheses named in the chapter; “read” means a declared reading; “open” means no link yet. “Translated” marks an exact one-to-one map (the same mathematics in two languages). “Axiom” marks a statement of N1–N7; “identified” marks a declared identity of a net object with a known object (I1–I4); “reduced” marks a number expressed by an identity through other numbers that remain open.

Term in physics	Term in the net	Status	Where
Vacuum, medium, ether	The strand seen as a whole of windings (“the net”); nothing besides the strand	Axiom (N1)	1.3
Light, photon	A location on the strand that moves one step per tick	Axiom (N6)	1.5
Length, time	References taken from a cycle; counts of steps and ticks	Axiom (N7)	1.5, 11
Speed of light c	One step per tick; in SI a conversion	Axiom (N6, N7)	14.1
Planck constant h, gravitational constant G	Conversions between human references	Axiom (N7)	11, 25.9
Dimensionless constant	Ratio of counts; the only target of a derivation	Axiom (N7)	11, 25.9

Term in physics	Term in the net	Status	Where
Stable particle	Closed winding	Read (C4)	15.2
Electron	One closed loop of light (double loop)	Identified (I1)	15.1
Spin ½	Return after 4π	Derived under the quaternion hypothesis (Foundations T21); identification with spin: read	7.3, 14.3
Electric charge, conserved	Winding number of the first knot (Hopf charge)	Derived under named hypotheses (Foundations T22)	7.4
Proton	Closure of three windings	Read	15.5
Quark	One of the three windings of a closure of three	Read	15.5
Fractional charge $2/3, -1/3$	Trinity divided by three	Read; values open	15.5
Confinement	N2: an open window does not persist	Read	15.5
Colour neutrality, triality zero	Closure $x + y + z \equiv 0 \pmod 3$	Translated (for up to three constituents)	15.5

Term in physics	Term in the net	Status	Where
Strong interaction, gluon	The closure between the three windings	Read	15.5
Binding energy, mass defect	Tension released at a closure	Read; amounts open	15.7
Mass (inertia)	Rate at which the light location turns back in a loop	Derived in 1+1 dimensions under H-D1 (B10); reading: read	25.2, 15.6
Mass (weight, gravitational charge)	Shift of the visit density around a loop	Read	15.6, 25.6
Equivalence principle	Inertia and weight are two counts of one loop	Read; open (R17)	15.6
Dirac equation	Quantum walk with reversal amplitude θ	Derived in 1+1 dimensions under H-D1 (B10)	25.2
$E^2 = p^2 + m^2$	Dispersion of the walk, $\cos\omega = \cos\theta\cos k$	Derived in 1+1 dimensions under H-D1 (B10)	25.2
Maxwell's equations	Quaternion difference structure on a flat net	Derived under H-Q1, H-Q2 (B9)	25.1
Gauge freedom	Scalar register of the quaternion field	Derived under H-Q1, H-Q2 (B9)	25.1

Term in physics	Term in the net	Status	Where
Gravity, static part	Scalar register: visit density	Read; sign derived under H-G1 (B14)	25.6, 25.9
Attraction of like masses	Positive field energy plus linear coupling	Derived under H-G1 (B14)	25.6
Newton's $1/r$	Limit of a finite range $\sqrt{\kappa/\bar{g}}$	Open (R16)	25.6, 25.7
Light deflection	Refraction (Snellius) in the index $1 + 2\varphi$	Derived under N6, H-S (input, $\gamma_{\mathrm{PPN}} = 1$) and the Newtonian potential (input) (B16)	25.8
Gravitomagnetism, frame dragging	—	Open (R18)	25.9
General relativity	Static scalar part and deflection only	Open (R18, R19)	13.6, 26
Local position invariance	Limit of N4 where the state does not vary	Read	13.6
Fine-structure constant α	—	Open (R1)	25.9
Mass ratio m_p/m_e	Ratio of loop lengths	Open (R2); read as a ratio of loop lengths	25.9

Term in physics	Term in the net	Status	Where
Gravity / electric force, 10^{-37}	$\left(m_p/m_{\mathrm{Pl}}\right)^2/\alpha$	Reduced (identity)	25.9
Energy density of a field	Rate function of the visit count	Hypothesis H-R; reading: read	25.7
Stiffness, coupling	Second and third derivative of the rate function	Derived under H-R and T24 (B15)	25.7
Entropy production	Located loss (Physics T6)	Known (de Groot–Mazur)	12
Atomic shell, $2n^2$	Count of closed states	Derived under input (B1)	16
Periodic table	Madelung order	Derived under input (B2)	17
Chemical bond	Closure between atoms (graph)	Derived: B3; under input or hypothesis: B4, B5; reading: read	18
Aromaticity, $4n + 2$	Ring closure	Derived under input (B11)	25.3
Hess's law	Path independence of closure	Derived under input (B6)	20
Radiative forcing, $\ln C$	Width of the thick band	Derived under H1–H4 (B12)	25.4
Climate sensitivity	State function λ (N4)	Read; values input	22.6, 23

Term in physics	Term in the net	Status	Where
Milankovitch cycles	Beats between windings of the planets and the Sun–Moon torque	Read	23.8

Appendix I — Standard Objections and Where the Book Answers Them

Readers trained in the standard literature, and language models trained on it, raise the same objections. This appendix lists them with the answer of the book and its status. It is meant to shorten discussion: each answer points to the place where the claim is made and to the status that the claim carries.

No.	Objection	Answer of the book	Status	Where
1	“This is numerology.”	Every number has a status. Fits are labelled as fits (G4). Rules for open numbers are fixed before computation (28.1). The proven results are structural theorems, listed in Appendix G, each checked by an independent judge, except Foundations T21 (Appendix D).	—	27, 28, App. D, G

No.	Objection	Answer of the book	Status	Where
2	“Nothing is derived; everything is assumed.”	The axioms N1–N7 and the named hypotheses are stated. Theorems B1–B16 follow by proof from them and from the inputs named in each theorem (Appendix G). What is input is called input.	—	1.3, App. F, G

No.	Objection	Answer of the book	Status	Where
3	“There is no medium; the ether was refuted.”	The book has no medium beside the strand (N1); “net” means the strand as a whole of windings (Appendix H). What was refuted is a medium with a detectable rest frame; whether the net has none in three dimensions is open (R14, R20).	Axiom; open (R20)	1.3

No.	Objection	Answer of the book	Status	Where
4	“A discrete net breaks Lorentz invariance.”	In 1+1 dimensions the walk of B10 gives the relativistic dispersion in the limit of small steps. In three dimensions this is open (R14). Measurements place the scale of a linear energy dependence of the light speed above 1.2 Planck energies (Fermi, GRB 090510).	Derived (1+1); open (3+1, R20)	25.2, 28.4

No.	Objection	Answer of the book	Status	Where
5	“Scalar theories of gravity were refuted (Nordström).”	The book agrees. The static scalar part gives the sign of attraction (B14). Light deflection needs H-S, which is input equivalent to $\gamma_{\mathrm{PPN}} = 1$ (B16). Frame dragging shows a vector part that is open (R18).	Derived under hypotheses; open	25.6, 25.8, 25.9

No.	Objection	Answer of the book	Status	Where
6	“General relativity is not reproduced.”	Correct. The book derives the static sign and, under input, the deflection. Perihelion shift and frame dragging are open (R18, R19). Where the book departs from general relativity (N4), it names the measured range in which both agree.	Open	13.6, 26, 28.4

No.	Objection	Answer of the book	Status	Where
7	"Where are c, $\hbar$ and G?"	By N7 they are conversions between human references, not properties of the net. Only dimensionless numbers are targets. Duff holds the same view in the debate on fundamental constants; Okun and Veneziano do not.	Axiom	1.5, 11, 25.9
8	"The book does not explain α or m_p/m_e."	Correct. Both are open (R1, R2). The ratio of gravity to electric force is reduced by an identity to α and m_{Pl}/m_p.	Open	25.9, 28.2

No.	Objection	Answer of the book	Status	Where
9	“Where are quarks, gluons and QCD?”	Read, not derived: three windings with charges in thirds; confinement as N2. Triality zero is translated: closure mod 3. The values and the masses are open (R2, R3, R4).	Read	15.5
10	“This is just the toroidal electron of Williamson and van der Mark.”	The electron is identified with that configuration (I1). The book does not claim that it yields 1836; that paper treats the electron only and does not give it either.	Identified	15.1, 25.9

No.	Objection	Answer of the book	Status	Where
11	“Where is quantum mechanics?”	The Dirac dispersion follows in 1+1 dimensions from the walk; complex amplitudes are hypothesis H-D1 (R13). The quantum of action is a conversion (N7).	Derived under H-D1; open (R13, R14)	25.2

No.	Objection	Answer of the book	Status	Where
12	“There are no testable predictions.”	Registered predictions P1, P3, P4 and P5 are stated with their present testability (there is no P2). P1 lies about 650 times (nearly three orders of magnitude) below present uncertainty. P3 equals the known MOND transition radius. P4 has no criterion or time horizon (GAP). P5(i) cannot be tested with any foreseeable experiment.	Registered	13, 14

No.	Objection	Answer of the book	Status	Where
13	“Why three?”	The closure of three trits is the ground (N2). Radix economy favours three; this agrees but does not prove it.	Ground; agreement	2.4
14	“Inertial and gravitational mass are equal by assumption in general relativity; why here?”	Both are counts of one loop. Their equality is not yet derived (R17).	Read; open	15.6
15	“Climate: the book ignores the Sun and the orbit.”	Section 23.8 treats the Sun, the orbit and the planets and compares them with the CO_2 forcing.	Computed; known	23.8