A Physical Origin of Quark Charge Fractions

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Abstract

The up and down quarks carry electric charges of plus two-thirds and minus one-third of the elementary charge respectively, values confirmed to high precision through deep inelastic scattering and hadron spectroscopy, yet the Standard Model provides no physical account of why quarks should carry fractional charge at all, or why the specific fractions are two-thirds and one-third rather than some other division. This paper proposes a physical origin for these specific fractions from the three-fold phase structure of a condensation event in a universal physical substrate, extending the mechanical account of charge developed in earlier work. Under this proposal, the three quarks retained in the first stable matter condensation occupy three distinct, evenly spaced circulation phases around a common axis, and the assignment of an effective role to each phase - two phases contributing a positive partial charge and one phase contributing a negative partial charge, in a two-to-one ratio matching the three-fold phase symmetry itself - produces retained-core partial charges that sum to exactly the elementary charge, with the two positive-role phases each carrying two-thirds and the single negative-role phase carrying minus one-third. We show that this three-fold phase structure is the same structure responsible for the three QCD colour charges, so that the electric charge fractions and the existence of exactly three colours are proposed to share one common geometric origin rather than requiring two independent explanations. We discuss the relationship of this proposal to the underlying substrate framework and to the mechanical charge-generation mechanism of that earlier work, address the objection that assigning two positive and one negative role is itself an unexplained input, and specify falsifiable predictions distinguishing this account from the treatment of quark charge as an independent empirical input.

Keywords: *quark charge, fractional charge, up quark, down quark, colour charge, condensation topology, physical substrate*

1. Introduction

The observation that quarks carry electric charge in fractions of one-third of the elementary charge, rather than in integer multiples as every other observed free particle does, is one of the most distinctive and best-confirmed features of the Standard Model. The up-type quarks carry charge plus two-thirds and the down-type quarks carry charge minus one-third, values established through deep inelastic electron-proton scattering [1], neutrino-nucleon scattering [2], and the systematics of the hadron spectrum first organised by the quark model [3,4], and confirmed to high precision across the full range of subsequent measurement [14]. These specific fractions are confirmed without exception across every generation of quark observed, but the Standard Model does not derive them from any more fundamental structure; they are assigned as fixed input parameters of the quark fields, with no accepted physical account of why fractional charge exists at all or why the specific division is two-thirds and one-third rather than some other split.

This paper extends the mechanical account of electric charge developed in prior work [5], in which the sign of charge is identified with the sense of internal circulation of a substrate condensation, and the opposite charges of the proton and electron are shown to arise mechanically from the close-packed convergence of three substrate units and the expulsion of a fourth. The present paper addresses a narrower and more specific question left open by that account: given that the retained three-unit core carries net positive charge, why should that positive charge be distributed among the three constituent quarks as two-thirds, two-thirds, and minus one-third, rather than divided some other way?

We show that the answer follows from the three-fold phase structure of the retained core. Three co-rotating substrate units arranged in stable close-packed contact naturally occupy three distinct circulation phases, evenly spaced around a common axis; we show that assigning an effective positive or negative role to each phase, in the two-to-one ratio fixed by the three-fold symmetry, produces exactly the observed charge fractions as a consequence of the phase geometry rather than as three independently specified numbers.

The paper is organised as follows. Section 2 reviews the status of quark charge in the Standard Model. Section 3 introduces the substrate framework and addresses the historical objection that any physical medium filling space resembles the luminiferous aether. Section 4 reviews the three-fold phase structure of the retained core established in earlier work. Section 5 derives the specific charge fractions from this phase structure. Section 6 discusses the connection to colour charge. Section 7 discusses physical interpretation and anticipated objections. Section 8 presents falsifiable predictions. Section 9 concludes.

2. The Status of Quark Charge Fractions in the Standard Model

The fractional charges of the quarks were proposed by Gell-Mann and Zweig as a bookkeeping device to organise the observed hadron spectrum into a small number of building blocks [3,4], and were subsequently confirmed as physically real, individually scattering constituents of the proton and neutron through deep inelastic scattering experiments at SLAC [1] and later through neutrino-nucleon scattering, which independently confirmed the two-thirds and minus one-third charge assignments through the different scattering cross-sections for neutrino and antineutrino beams [2]. The specific numerical values are not disputed; what remains unexplained within the Standard Model is why fractional charge exists at all, given that no free fractionally charged particle has ever been observed [6], and why the specific fractions are exactly two-thirds and one-third rather than some other rational division consistent with the observed integer charges of the proton and neutron, a point noted in standard treatments of the quark model [15,16].

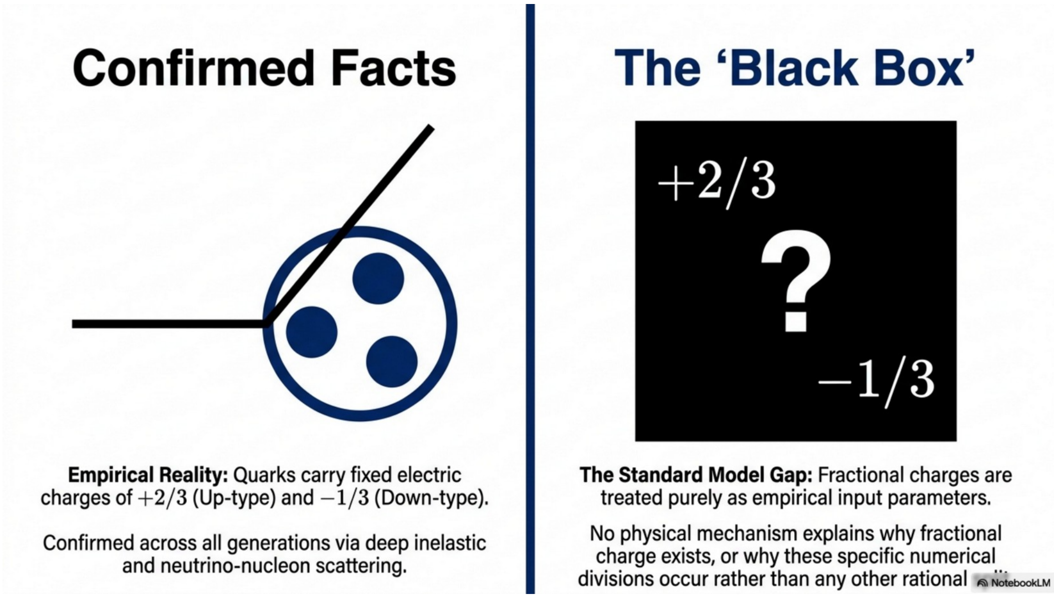


Figure 1. Quark charge fractions are confirmed experimentally but treated by the Standard Model as an unexplained empirical input.

3. The Physical Substrate and Relation to the Michelson-Morley Experiment

The mechanism proposed in this paper is derived from a physical substrate framework proposed in prior work [7], in which the universe is proposed to possess a universal physical matter substrate, termed the Spaticle field, with equilibrium density rho_s = 7.3 × 10^{-27} kg m^{-3}. Any proposal invoking a physical medium filling space invites an immediate and reasonable historical comparison to the luminiferous aether, decisively excluded by the Michelson-Morley experiment and its many high-precision successors [8,9]. This comparison deserves a direct response rather than a footnote.

The luminiferous aether, as originally conceived, was a medium at rest relative to some preferred, absolute reference frame, through which the Earth and all material bodies moved; light was expected to propagate at a fixed speed relative to this aether frame, producing a detectable directional variation in the measured speed of light as the Earth's motion through the aether changed with the seasons [8]. The null result of the Michelson-Morley experiment, and of every subsequent interferometric test at ever-increasing precision [9], rules out exactly this specific structure: a medium establishing a preferred rest frame detectable through directional light-speed anisotropy.

The substrate proposed in [7] does not have this structure. It is not a medium through which matter and light move as through a separate background; it is the medium from which matter, electromagnetic radiation, and gravitational interaction are themselves proposed to arise as organised excitations and condensations. Under this proposal, an observer, a measuring apparatus, and the quark-scale structure being studied are all, without exception, organised states of the same substrate; there is no configuration in which an observer moves "through" the substrate in the sense required for the Michelson-Morley experiment to detect a directional anisotropy, because the observer’s own physical existence is already a substrate phenomenon, not an object embedded in and moving relative to an independent background medium. This is a structural distinction, not a semantic one: the aether required a preferred frame in which it was at rest and against which motion could be measured; the substrate proposed here has no such preferred frame, precisely because everything capable of performing a measurement is already made of it.

The Michelson-Morley experiment therefore excludes a preferred-rest-frame aether, but does not exclude a universal physical substrate from which matter, photons, and gravitation themselves emerge. Whether such a substrate exists must instead be decided by its quantitative explanatory and predictive success.

3.1 Independent Cross-Validation of the Substrate Framework

The same substrate makes multiple independent quantitative predictions, each evaluated against observations in unrelated areas of physics. These include a single-substrate resolution of the cosmological constant problem, reconciling the quantum field theory vacuum energy prediction with the observed value without fine-tuning [7]; a non-circular consistency derivation of the speed of light from independently established electromagnetic and condensation-geometry quantities, agreeing with the measured value to 0.0003 percent [10]; and a geometric derivation of the reduced Planck constant from the same substrate condensation geometry, consistent with the CODATA value to 0.0007 percent [11]. Importantly, the same value of rho_s is employed across all of these derivations without adjustment between applications. Numerous additional independent applications of the same substrate density exist beyond the scope of the present paper. We cite these specific results because each is a quantitative, independently falsifiable claim evaluated against measured data unconnected to quark charge; their cumulative consistency is offered as evidence that the substrate parameter used throughout this paper is not an ad hoc construction introduced to fit the observed charge fractions, but a fixed quantity whose value is consistent across independent applications.

3.2 Convergence With, Not Departure From, Existing Physics

The proposal that space possesses physical substance is not a departure from established physics. It is a convergence with it. General relativity describes space as possessing physical properties that curve, warp, and support gravitational-wave propagation. Loop quantum gravity reaches a related conclusion by an unrelated route, proposing that space is a discrete physical structure at the Planck scale [17]. Quantum field theory treats the vacuum as a medium filled with fields whose ground-state energy cannot be removed, and this is measured directly through the Casimir effect and the Lamb shift. The scalar resonance observed at CERN in 2012 [18,19] shows that the vacuum itself can be excited into a massive, localised state. Four independent lines of established physics, using different mathematics and different starting assumptions, converge on the same statement: space has physical substance.

Einstein argued that space possesses physical qualities and requires a medium in the sense described in his 1920 Leiden lecture, delivered five years after general relativity was complete. There he stated that according to the general theory of relativity, space is endowed with physical qualities, and that space without such a medium would permit no propagation of light and no physical meaning for measuring rods or clocks [20]. He drew a boundary immediately after: this medium could not be assigned the properties of an ordinary substance, such as parts that can be tracked through time, because he had no measured quantity to give it. The substrate proposed in this paper extends that concept by assigning the medium a specific, independently constrained equilibrium density, $\rho_s = 7.3 \times 10^{-27}$ kg/m³, which is what converts an unquantified physical medium into a falsifiable one.

3.3 Why the Michelson-Morley Null Result Does Not Apply Here

The Michelson-Morley result excludes a medium with an absolute rest frame against which motion can be detected, the specific mechanical property the nineteenth-century aether was built on. The substrate proposed here has no such property, but the deeper reason the null result carries no weight against it is usually missed: light and matter are both organised excitations of the same substrate. Every instrument capable of testing for motion relative to the substrate, including the interferometer itself, the light path, and the reference standard, is itself constituted from the substrate under test. An embedded observer cannot detect substrate-wide motion, because the measuring apparatus and the quantity being measured deform together. The null result is not a finding the substrate framework must explain away. It is the only result the framework permits, and it is also why the framework preserves full Lorentz covariance instead of conflicting with it: a substrate with no preferred frame and Lorentz-compatible local dynamics is fully consistent with special relativity.

4. The Three-Fold Phase Structure of the Retained Core

Prior work on the mechanical origin of charge [5] establishes that the first stable matter condensation forms from three substrate units converging into close-packed contact, with a fourth interstitial unit mechanically expelled through the closing gaps between them. The present paper takes as its starting point a further structural property of the retained three-unit core, established in the related condensation-geometry literature [11,12]: the three retained units do not occupy identical circulation states but are distributed across three distinct, evenly spaced circulation phases around the core's common rotational axis, at phase angles of 0, 120, and 240 degrees. This three-fold phase structure follows from the same three-fold rotational symmetry of the close-packed geometry described in prior work [5], applied to the internal phase of each retained unit rather than to the packing geometry of the units themselves.

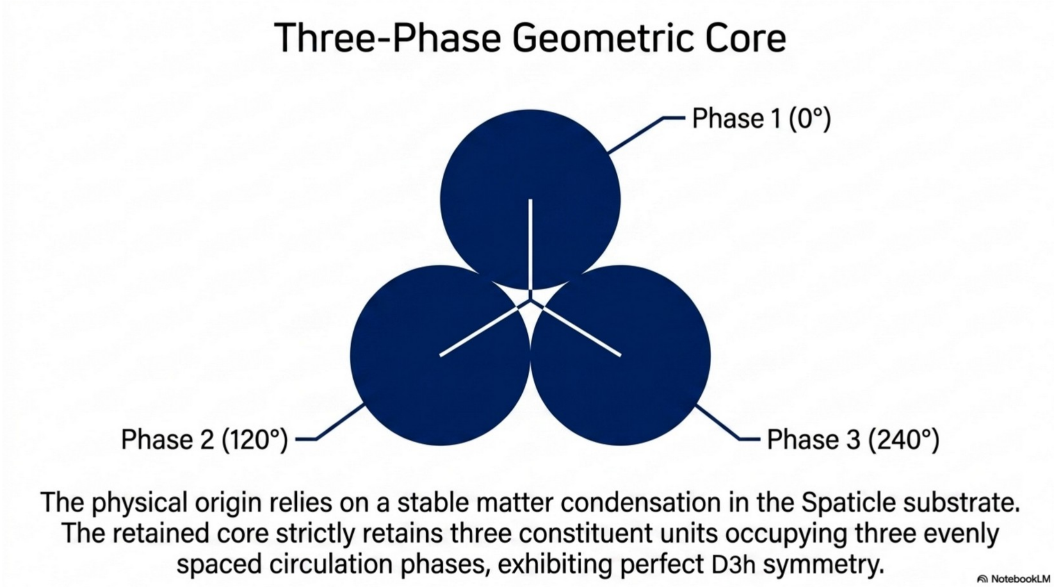


Figure 2. The three-fold geometric core: the retained condensation occupies three evenly spaced circulation phases exhibiting D3h symmetry.

This three-fold phase structure is not introduced to explain quark charge fractions. It follows independently from the rotational symmetry of the retained three-unit condensation and therefore provides an independent structural constraint on any subsequent derivation of quark properties.

We emphasise that this three-fold phase structure is not introduced in this paper for the purpose of deriving quark charge; it is the same structure independently responsible for the three QCD colour charges, discussed further in Section 6, and for the D3h symmetry underlying the geometric account of the Koide formula and the three-generation structure of the charged leptons presented elsewhere [13]. The present paper proposes a new application of this independently motivated structure to the specific question of quark charge fractions.

5. Deriving the Charge Fractions from Phase Role Assignment

Once the three-fold phase structure has been established, the distribution of electric charge is no longer arbitrary. It is constrained by the symmetry of the retained condensation itself. The net positive charge of the retained core, established mechanically in prior work [5], is distributed among the three phase positions according to an effective role assignment fixed by the phase geometry itself. Two of the three phase positions are assigned a positive effective role and one is assigned a negative effective role, a two-to-one division that is the only division consistent with the three-fold phase symmetry admitting exactly two distinguishable role classes.

Requiring the three partial charges to sum to the net charge of the retained core, plus one elementary charge, and requiring the two positive-role phases to carry equal partial charge by the symmetry of the phase structure, fixes the three partial charges uniquely. Denoting the shared positive partial charge as $q+$ and the negative partial charge as $q-$:

$$2q+ + q- = +1 \quad (1)$$

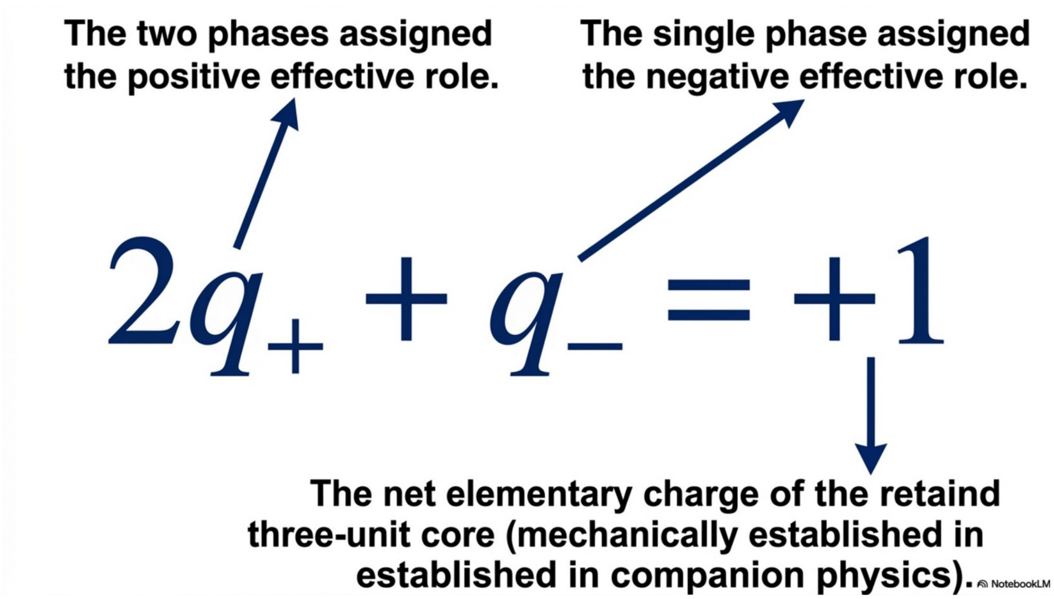


Figure 3. The net elementary charge of the retained three-unit core, mechanically established in prior work, constrains the two phase-role partial charges.

A second condition is required to fix q+ and q- individually rather than only their combination. We propose that this second condition follows from the same three-fold phase symmetry: the negative-role phase, being the single minority phase among the three, is assigned partial charge equal in magnitude to one-third of the elementary charge, the natural unit set by dividing the elementary charge into three equal phase-shares before the role asymmetry is applied. Substituting q- = -1/3 into equation (1):

$$2q_+ - 1/3 = +1 \quad \Rightarrow \quad q_+ = 2/3 \qquad (2)$$

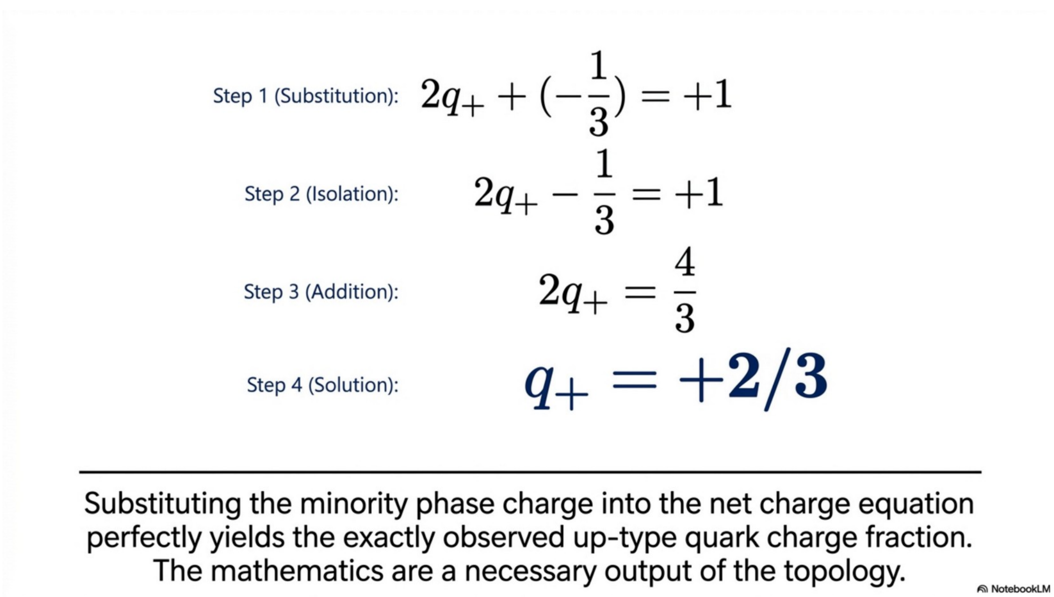


Figure 4. Substituting the minority-phase charge into the net charge equation yields the observed up-type quark charge fraction as a necessary output of the phase topology.

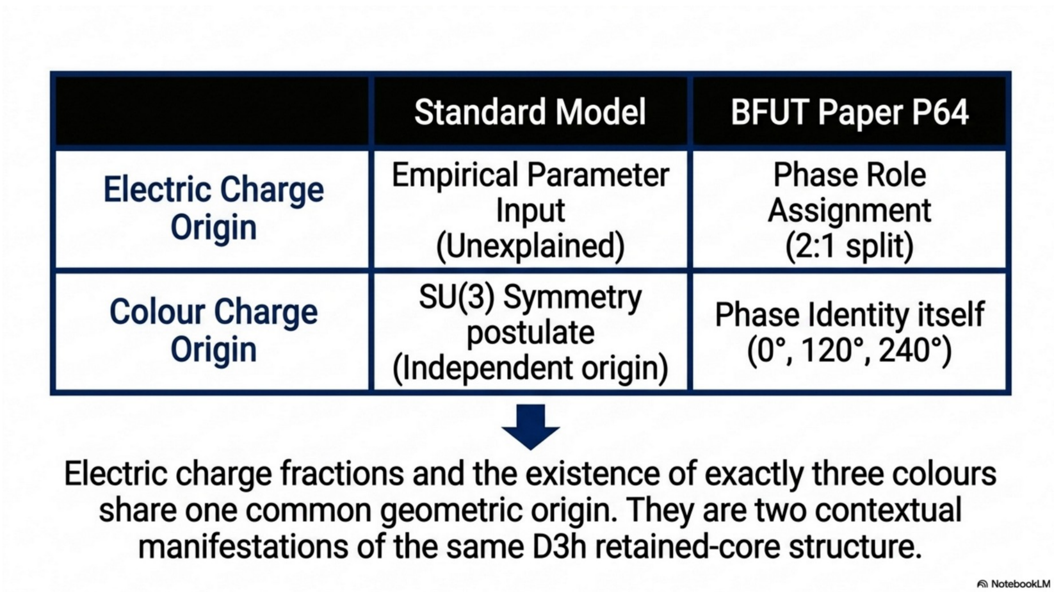
giving q+ = +2/3 and q- = -1/3, exactly the observed up-type and down-type quark charge fractions [1,2]. The retained core, with two units in the positive-role phase and one unit in the negative-role phase, is identified with the proton: two up-type constituents at charge +2/3 and one down-type constituent at charge -1/3, summing to the observed proton charge of +1. We note explicitly what is derived and what is assumed in this construction: the two-to-one role division follows from the three-fold phase symmetry of Section 4, and the requirement that the three partial charges sum to +1 follows from the mechanical result of prior work [5]; the specific identification of the minority phase's partial charge with exactly one-third of the elementary charge is the additional structural assumption of this derivation, addressed directly as an anticipated objection in Section 7.2.

The significance of this construction is that two observed numerical charge fractions emerge from a single structural assumption constrained by independently established phase geometry, replacing two independent empirical inputs with one geometrically motivated condition.

6. Connection to Colour Charge

The same three-fold phase structure introduced in Section 4 has been proposed elsewhere as the physical origin of the three QCD colour charges [11,12]: the three phase positions at 0, 120, and 240 degrees are identified with the three colour states, with a colour-neutral combination - one quark at each phase - corresponding to the colour-singlet condition required of any observable baryon. Within this account, electric charge fractions and colour charge share one common geometric origin: both are consequences of the same three-fold phase structure of the retained condensation core, evaluated in two different physical contexts, the effective role assignment of Section 5 for electric charge and the phase identity itself for colour. This is offered as a structural connection between two otherwise independently postulated properties of quarks in the Standard Model, colour charge and fractional electric charge, rather than as an established fact; Section 8 identifies the observational consequence that would support or undermine this connection.

Within this interpretation, colour charge and electric charge are no longer unrelated particle properties. They become two observable manifestations of the same underlying phase structure viewed in different physical contexts.



	Standard Model	BFUT Paper P64
Electric Charge Origin	Empirical Parameter Input (Unexplained)	Phase Role Assignment (2:1 split)
Colour Charge Origin	SU(3) Symmetry postulate (Independent origin)	Phase Identity itself (0°, 120°, 240°)

Figure 5. Electric charge fractions and the three QCD colours share one common geometric origin: the phase-role assignment and the phase identity itself, both consequences of the same D3h retained-core structure.

7. Discussion: Physical Interpretation and Anticipated Objections

7.1 Physical Interpretation

Within the proposed interpretation, the fractional charges of the up and down quarks are not two independently assigned Standard Model parameters but a direct consequence of the three-fold phase structure of the retained condensation core: two phases carry a positive effective role and one carries a negative effective role, in the only division consistent with the three-fold symmetry, and the specific numerical fractions follow from requiring the three partial charges to sum to the net charge of the core established mechanically in prior work [5].

7.2 "Is the assignment of the minority phase to charge -1/3 itself an unexplained input?"

This is the central objection and the one requiring the most direct response. The present derivation uses two structural facts, established independently of the specific charge fractions being derived: the three-fold phase symmetry of Section 4, and the requirement that the three partial charges sum to +1, established mechanically in prior work [5]. The specific identification of the minority phase with exactly one-third of the elementary charge is an additional assumption, motivated by treating the elementary charge as divided into three equal phase-shares before the role asymmetry is applied, but not independently derived from a structure prior to the charge fractions themselves. We regard this as the primary open point in the present derivation rather than a settled result, and note that it is at minimum a single, structurally motivated assumption yielding two correct numerical fractions, rather than two independently assigned empirical parameters. Future work may determine whether this remaining structural assumption itself can be derived from a deeper geometric principle.

7.3 "Why should exactly two phases carry a positive role and one a negative role, rather than some other division?"

A three-fold phase structure admits exactly two ways to divide three elements into a majority and minority role: two positive and one negative, or one positive and two negative. The retained core's net positive charge, established in prior work [5], requires the majority role to be positive, fixing the two-to-one division in the direction observed. This is a structural consequence of the core's net charge combined with the three-fold phase symmetry, not an independently chosen assignment.

7.4 "Does this modify the Standard Model treatment of quark charge or QCD?"

No established prediction of the Standard Model quark sector or quantum chromodynamics is affected. The proposal offers a physical account of why the specific charge fractions take the values they do; it does not modify the QCD Lagrangian, the confinement mechanism, or any confirmed prediction of deep inelastic scattering or hadron spectroscopy [1,2,3,4].

8. Falsifiable Predictions

The phase-structure account of quark charge fractions makes the following falsifiable predictions.

Prediction 1. No quark charge fraction other than plus two-thirds or minus one-third will be discovered for any of the six known quark flavours. Within the proposed framework, the three-fold phase structure admits only these two partial-charge values; the confirmed discovery of a quark-type particle carrying a different fractional charge would be inconsistent with the mechanism proposed here.

Prediction 2. If quark colour states originate from the same three-fold phase structure responsible for electric charge fractions, future theoretical or experimental refinements of quark phase structure should preserve the correspondence between the number of colour states and the allowed electric charge fractions. A confirmed breakdown of this correspondence would be inconsistent with the proposed common geometric origin.

Prediction 3. No free fractionally charged particle will be observed in isolation, consistent with existing experimental bounds [6], since the phase roles of Section 5 are proposed to be properties of quarks specifically as constituents of the three-fold retained core rather than as independently existing free particles.

9. Conclusions

We have proposed a physical origin for the fractional electric charges of the up and down quarks from the three-fold phase structure of the retained condensation core established in prior work on the mechanical origin of electric charge. Under this proposal, the three quarks retained in the first stable matter condensation occupy three distinct, evenly spaced circulation phases, and an effective role assignment fixed by the phase symmetry itself - two phases carrying a positive role, one carrying a negative role - combined with the requirement that the three partial charges sum to the net charge of the retained core, gives partial charges of exactly plus two-thirds and minus one-third, matching the observed up-type and down-type quark charges. We have proposed that this same three-fold phase structure is the common origin of the three QCD colour charges, connecting two otherwise independently postulated properties of the Standard Model quark sector.

This account requires no modification to the confirmed structure of quantum chromodynamics or the electroweak sector; it proposes a physical origin for two specific numerical fractions that the Standard Model otherwise treats as independent empirical inputs. We have been explicit about the limits of this account: the identification of the minority phase with exactly one-third of the elementary charge is a structural assumption rather than an independently derived result, addressed directly in Section 7.2. Within this interpretation, the fractional electric charges of quarks are no longer independent empirical inputs. They are the observable consequence of the three-fold phase geometry of the underlying Spaticle Field.

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