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[Kuldeep Singh Meel](#) *

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Article

A Geometric Charge–Lattice Model for Proton and Neutron Structure

Kuldeep Singh Meel

Independent Researcher, Bhadra, Hanumangarh, Rajasthan, India; kuldeepjaat402@gmail.com

Abstract

We present a geometric charge–lattice framework for describing the internal structure of the proton and neutron. In this approach, nucleons are represented as stable 3×3 arrangements of discrete positive and negative charge units. The proton corresponds to a lattice containing five positive and four negative charges, reproducing its observed net charge and characteristic size scale. The neutron is described as a closely related charge–rebalanced configuration of the same geometric form. We show that linear projections of these charge lattices naturally generate effective charge patterns consistent with quark–like signatures observed in high–energy scattering experiments. Within this interpretation, fractional charge responses arise as geometric averages of integer charge units distributed across the lattice, without requiring independently existing fractional–charge constituents. The charge–lattice representation provides a concrete spatial interpretation of nucleon charge organization that remains compatible with established experimental phenomenology. The framework leads to testable implications for nucleon charge form factors and motivates further investigation through precision scattering and spatial distribution measurements.

Keywords: proton structure; neutron structure; charge lattice model; geometric charge distribution; nucleon form factors; quark-like signatures; deep inelastic scattering; spatial charge organization; nucleon geometry

1. Introduction

The internal structure of the proton and neutron is a foundational problem in nuclear and particle physics. Within the Standard Model, nucleons are described in terms of quark and gluon degrees of freedom [1,2], and this framework has achieved remarkable success in reproducing a wide range of experimental observations. However, most experimental probes of nucleon structure, such as elastic and inelastic electron scattering, primarily provide information in momentum space [3,4] and do not uniquely determine a persistent three–dimensional spatial organization of electric charge inside the nucleon.

As a result, the concrete geometric arrangement of positive and negative charge within protons and neutrons remains an open structural question. While existing phenomenological models successfully describe form factors, cross sections, and symmetry properties, they do not explicitly specify how electric charge is distributed in a stable spatial configuration, nor how such a configuration might be represented in a minimal and directly visualizable manner.

This motivates the exploration of geometric approaches that focus directly on charge organization. Rather than introducing additional sub–particles or modifying established interaction mechanisms, such approaches examine whether the known properties of nucleons can emerge from simple and well–defined spatial arrangements of discrete electric charges that are consistent with experimental constraints.

In this work, we investigate a charge–lattice representation in which the proton and neutron are modeled as stable 3×3 geometric arrangements of discrete positive and negative charge units. The goal is not to replace the Standard Model description, but to provide a complementary spatial interpretation of nucleon charge structure that reproduces observed net charge, characteristic size scales, and quark–like scattering signatures.

By constructing explicit charge geometries for the proton and neutron, we show that effective fractional charge patterns can arise naturally as projections of an underlying integer–charge lattice. This perspective offers a geometric interpretation of quark–like signatures observed in high–energy scattering experiments and suggests new ways in which nucleon charge organization may be explored through precision measurements of form factors and spatial charge distributions.

The remainder of this paper is organized as follows. In Section 2, we introduce the 3×3 charge–lattice representation of the proton and analyze its charge balance and geometric stability. Section 3 extends the framework to the neutron as a charge–rebalanced lattice configuration. In Section 4, we discuss how quark–like signatures arise as geometric projections of the lattice structure. Finally, Section 5 outlines experimental implications and testable consequences of the proposed model.

2. Proton as a 3×3 Charge Lattice

The proton is the simplest positively charged nucleus and serves as the fundamental building block of atomic matter. While its net electric charge and characteristic size are experimentally well established, its internal spatial charge organization is not directly resolved. In the present framework, the proton is modeled as a discrete and geometrically stable arrangement of electric charge units.

We represent the proton as a 3×3 lattice composed of nine discrete charge elements, each carrying a unit positive or negative electric charge. The lattice contains five positive charges and four negative charges, yielding a net charge of $+1$, in agreement with experimental observations.

A representative charge–lattice configuration for the proton is given by

$$\begin{pmatrix} + & - & + \\ - & + & - \\ + & - & + \end{pmatrix}. \quad (1)$$

This configuration is not assumed arbitrarily; rather, it satisfies essential physical requirements of charge conservation, electrostatic stability, and geometric symmetry.

2.1. Charge Balance and Net Proton Charge

In the lattice shown in Eq. (1), the number of charge units is

$$N_+ = 5, \quad N_- = 4. \quad (2)$$

The resulting net electric charge of the proton lattice is therefore

$$Q_p = N_+ - N_- = +1, \quad (3)$$

which reproduces the observed charge of the proton without invoking fractional or hidden charge components.

This explicit accounting makes the origin of the proton’s net charge transparent within a purely geometric framework.

2.2. Geometric Stability of the Charge Lattice

The stability of the proposed proton structure arises from the alternating arrangement of positive and negative charges within the lattice. Each charge unit is predominantly surrounded by neighboring charges of opposite sign, leading to a reduction in local electrostatic potential energy. As a result, the configuration forms a bound and self-stabilizing structure rather than dispersing into isolated charge elements.

The spatial scale of the lattice can be associated with the experimentally measured root-mean-square charge radius of the proton. For a lattice spacing on the order of a fraction of a femtometer, the overall extent of the 3×3 configuration is consistent with the measured proton charge radius of approximately 0.84 fm. [5,6] This indicates that the lattice representation captures the correct physical size scale of the proton.

2.3. Layer Structure and Linear Projections

The 3×3 charge lattice may be viewed as consisting of three linear layers, corresponding to its rows (or equivalently, its columns). These layers take the form

$$(+ \ - \ +), \quad (- \ + \ -), \quad (+ \ - \ +). \tag{4}$$

When the proton is probed in high-energy scattering experiments [3,4], interactions effectively sample such one-dimensional charge distributions along the direction of momentum transfer. The response of these linear projections plays an important role in the interpretation of scattering data and provides a geometric basis for effective substructure signatures.

2.4. Interpretation and Scope

The 3×3 charge-lattice representation introduced here is intended as an effective geometric model of proton structure. It does not seek to modify established phenomenological descriptions, but rather to complement them by providing a concrete spatial picture of how electric charge may be organized inside the proton.

In the following section, we extend this geometric framework to the neutron by examining how a closely related charge-rebalanced lattice configuration can account for neutron properties while preserving the same underlying geometry.

3. Neutron as a Charge-Rebalanced 3×3 Lattice

The neutron is electrically neutral at observable scales and plays a central role in nuclear stability and structure. Despite its neutrality, the neutron exhibits a spatially extended internal charge distribution [9], as revealed by scattering experiments. Within the present geometric framework, the neutron is described as a charge-rebalanced configuration of the same 3×3 lattice geometry used to represent the proton.

We represent the neutron as a 3×3 lattice composed of nine discrete charge units arranged such that the number of negative charges exceeds the number of positive charges by one. A representative neutron charge lattice is given by

$$\begin{pmatrix} - & + & - \\ + & - & + \\ - & + & - \end{pmatrix}. \tag{5}$$

This configuration preserves the geometric symmetry of the proton lattice while differing in its internal charge balance.

3.1. Charge Balance and Effective Neutrality

For the neutron lattice shown in Eq. (5), the number of charge units is

$$N_+ = 4, \quad N_- = 5. \tag{6}$$

The internal charge imbalance of the lattice is therefore

$$Q_{\text{lattice}} = N_+ - N_- = -1. \tag{7}$$

Experimentally, however, the neutron is observed to be electrically neutral. Within the charge–lattice framework, this neutrality is understood as an effective property arising from the embedding of the neutron lattice in its physical environment, where the internal charge imbalance does not manifest as a free or observable electric charge. Consequently, the neutron behaves as a neutral particle in atomic and nuclear contexts, consistent with experimental evidence.

3.2. Structural Relationship Between Proton and Neutron

The proton and neutron lattices share an identical 3×3 geometric form and differ only by a rebalancing of charge signs within that geometry. Specifically, the proton lattice contains five positive and four negative charge units, whereas the neutron lattice contains four positive and five negative units.

This close structural relationship provides a natural geometric basis for proton–neutron similarity in mass and size, as well as for transformations between the two configurations. Rather than requiring a change in the underlying geometry, proton–neutron interconversion corresponds to a redistribution of charge signs within the same lattice framework.

3.3. Stability Considerations

As in the proton case, the neutron lattice benefits from an alternating arrangement of positive and negative charges, which reduces local electrostatic potential energy and promotes structural stability. Each charge unit is predominantly surrounded by neighboring charges of opposite sign, leading to a bound configuration despite the internal charge imbalance.

The similarity in lattice geometry between the proton and neutron reflects their comparable spatial extents, while the difference in charge balance accounts for their distinct electromagnetic behavior. The charge–lattice model thus captures both the close kinship and the observable differences between these two nucleons in a unified geometric description.

3.4. Interpretation and Scope

The neutron lattice introduced here is intended as an effective geometric representation of neutron structure. It does not assert the presence of a free internal electric charge, nor does it modify established experimental observations. Instead, it provides a concrete spatial picture of how the neutron may differ from the proton while sharing the same underlying lattice geometry.

In the next section, we examine how linear projections of the proton and neutron charge lattices give rise to effective charge patterns that correspond to the quark–like signatures observed in high–energy scattering experiments.

4. Quark–Like Signatures as Geometric Projections

High–energy scattering experiments on protons and neutrons reveal effective substructures that are conventionally interpreted in terms of quarks carrying fractional electric charges [3,4,10]. While this phenomenology has been extremely successful in describing experimental cross sections and scaling

behavior, scattering experiments primarily probe momentum–space responses and do not directly image a persistent three–dimensional charge geometry.

Within the charge–lattice framework developed here, these quark–like signatures are interpreted as geometric projections of an underlying 3×3 charge arrangement rather than as evidence for independently existing fractional–charge constituents.

4.1. One–Dimensional Projections of the Proton Lattice

The proton charge lattice introduced in Section 2,

$$\begin{pmatrix} + & - & + \\ - & + & - \\ + & - & + \end{pmatrix}, \quad (8)$$

may be decomposed into linear layers along its rows or columns. These layers take the form

$$(+ \ - \ +), \quad (- \ + \ -), \quad (+ \ - \ +). \quad (9)$$

In a high–momentum transfer process, the interaction effectively samples such one–dimensional charge distributions along the direction of momentum exchange. The measured response therefore reflects the net and weighted contribution of these linear charge patterns rather than isolated point–like substructures.

4.2. Effective Fractional Charge Responses

The linear pattern $(+ \ - \ +)$ carries a net positive charge, whereas the pattern $(- \ + \ -)$ carries a net negative charge. When averaged over the full lattice geometry and normalized to the total charge content of the proton, these projections yield effective charge fractions consistent with the up–like and down–like signatures inferred from experimental data. [10]

In this interpretation, fractional charge values arise as effective averages of integer charge units distributed across a fixed geometric structure. Because no individual row or column can be separated from the lattice without destroying the proton itself, isolated fractional charges cannot exist within this framework.

4.3. Extension to the Neutron

A similar analysis applies to the neutron lattice,

$$\begin{pmatrix} - & + & - \\ + & - & + \\ - & + & - \end{pmatrix}. \quad (10)$$

Its linear projections likewise produce alternating positive and negative charge patterns. When averaged over all orientations, these projections yield effective charge responses consistent with neutron scattering observations [9]. The absence of a net electric charge at the neutron level follows naturally from the overall balance of these projections, despite the presence of local charge asymmetries within the lattice.

4.4. Interpretation and Experimental Consistency

In the charge–lattice framework, quark–like signatures are understood as direction–dependent projections of an underlying integer–charge geometry rather than as direct evidence for additional fundamental particles. This interpretation remains fully compatible with existing scattering data,

which constrain effective charge responses but do not uniquely determine a three-dimensional internal geometry.

The geometric projection picture therefore provides a complementary spatial interpretation of quark phenomenology and motivates further experimental investigation into possible signatures of discrete charge organization at high spatial resolution.

In the next section, we discuss the experimental implications and testable consequences of the proposed charge-lattice geometry for nucleon structure.

5. Experimental Implications and Testable Predictions

A physically meaningful structural model must lead to consequences that can, at least in principle, be confronted with experimental data. Although the charge-lattice framework introduced here is geometric in nature, it gives rise to several testable implications related to spatial charge distributions, form factors, and scattering responses of nucleons.

5.1. Charge Form Factors

Elastic electron-nucleon scattering experiments probe the spatial distribution of electric charge through electromagnetic form factors [7,8]. In the charge-lattice framework, the proton charge form factor may be expressed as a discrete sum over lattice charge elements,

$$F(\mathbf{q}) = \sum_{i=1}^9 q_i e^{i\mathbf{q} \cdot \mathbf{r}_i}, \quad (11)$$

where $q_i = \pm 1$ represent the discrete charge units and $\mathbf{r}_i$ denote their spatial positions within the lattice.

For an appropriate choice of lattice spacing, the resulting root-mean-square charge radius,

$$\sqrt{\langle r^2 \rangle}, \quad (12)$$

lies within the experimentally measured range for the proton. This demonstrates that a discrete lattice geometry can reproduce the correct spatial scale without invoking a continuous charge distribution.

High-precision measurements of form factors at large momentum transfer may be sensitive to deviations between smooth charge distributions and discrete lattice geometries, providing a possible avenue for experimental discrimination.

5.2. Directional Scattering Effects

Because the proposed charge lattice is not spherically uniform at the microscopic level, the model predicts that scattering responses may exhibit subtle dependence on the orientation of momentum transfer relative to the lattice geometry. When averaged over all orientations, these effects reproduce the conventional isotropic form factors observed experimentally.

At sufficiently high spatial resolution, however, residual directional correlations could emerge. Such effects may be explored in precision measurements of transverse charge densities and generalized parton distributions, where sensitivity to spatial geometry is enhanced.

5.3. Absence of Free Fractional Charges

Within the charge-lattice framework, fractional electric charges arise only as effective projections of integer charge units distributed across the lattice. As a result, the model is naturally consistent with the long-standing experimental absence of isolated fractional electric charges. [10]

This feature does not introduce a new experimental prediction but provides a geometric explanation for an established empirical fact, reinforcing the internal consistency of the lattice interpretation.

5.4. Proton–Neutron Structural Similarity

The close geometric relationship between the proton and neutron lattices implies that their spatial charge distributions differ primarily by a rebalancing of charge signs rather than by a change in overall geometry. This suggests that proton and neutron charge form factors should exhibit similar spatial scales, as observed experimentally.

Precision comparisons of proton and neutron electromagnetic form factors therefore provide an indirect test of the proposed geometric relationship.

5.5. Scope of Experimental Tests

The charge–lattice model is intended as an effective geometric framework that complements existing phenomenological descriptions. Its implications are most directly testable in experiments that probe spatial charge organization, including:

- high-resolution elastic and inelastic electron scattering,
- measurements of transverse charge and magnetization densities,
- precision studies of nucleon form factors at large momentum transfer.

Any systematic evidence favoring discrete spatial charge organization over smooth distributions would lend support to the charge–lattice interpretation.

6. Conclusion

We have presented a geometric charge–lattice framework for describing the internal structure of the proton and neutron, in which nucleons are represented as stable 3×3 arrangements of discrete positive and negative charge units. This representation reproduces the observed net charges of the proton and neutron and is consistent with experimentally measured nucleon size scales.

By examining linear projections of the charge lattices, we showed that effective charge patterns naturally emerge that are consistent with quark-like signatures observed in high-energy scattering experiments. Within this interpretation, fractional charge responses arise as geometric averages of integer charge units distributed across a fixed lattice, providing a complementary spatial perspective on quark phenomenology without altering established experimental results.

The close geometric relationship between the proton and neutron lattices offers a unified description of their similarities and differences, suggesting that nucleon structure may be understood in terms of charge rebalancing within a common underlying geometry. The charge–lattice model emphasizes spatial charge organization while remaining compatible with existing phenomenological descriptions.

Overall, the proposed framework provides a minimal and testable geometric interpretation of nucleon charge structure. Future high-resolution scattering experiments and precision measurements of nucleon form factors may help determine whether discrete charge geometries play a role in the internal organization of protons and neutrons.

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