**Electromagnetic Structures — Part II**

# An Electromagnetic Supertorus as a Model of the Electron

Franc Rozman & UI


## Abstract

*Can Maxwell's equations describe not only propagating electromagnetic waves, but also stable localized structures resembling elementary particles? This question has accompanied classical electrodynamics since Maxwell's theory was first formulated, yet only a limited class of electromagnetic configurations has been explored in detail.*

*This work investigates the possibility that Maxwell's equations may admit stationary vacuum solutions in which electromagnetic fields organize themselves into a coherent hierarchy of toroidal structures. The proposed model consists of multiple coupled toroidal cells forming a closed electromagnetic supertorus. Local oscillations of the electric and magnetic fields are combined through phase locking into a globally coherent configuration with continuous circulation of displacement current and electromagnetic energy.*

*Rather than modifying Maxwell's equations, the model examines whether their existing solution space may contain previously unexplored stationary finite-energy structures. Observable properties such as effective electric charge, total electromagnetic energy, magnetic moment, and angular momentum are interpreted as collective properties of the complete electromagnetic configuration rather than of its individual components.*

*Instead of adjusting model parameters to reproduce known particle properties, the experimentally measured characteristics of the electron are treated as boundary conditions that any admissible electromagnetic solution must satisfy. This inverse approach transforms the proposed supertorus from a purely geometrical construction into a quantitatively testable physical hypothesis.*

*The present work does not claim that such stationary solutions have already been found. Rather, it formulates the mathematical and physical conditions that any viable solution must satisfy and identifies the principal theoretical challenges for future analytical and numerical investigation. If solutions of this type exist, they would extend the known family of Maxwell solutions and offer a new perspective on the electromagnetic organization of elementary particles.*


***Keywords****: Maxwell equations, stationary electromagnetic fields, toroidal electromagnetic structures, supertorus, coherent electromagnetic modes, displacement current, electromagnetic energy circulation, elementary particles.*

## 1. Introduction

Electromagnetic waves are generally described as propagating solutions of Maxwell's equations that extend through space while continuously transporting energy. In our previous work, we proposed that under appropriate conditions an electromagnetic wave may also form a localized toroidal configuration in which the electric and magnetic fields remain dynamically balanced. In such a structure, electromagnetic energy is continuously exchanged between the electric and magnetic fields, while the Poynting vector circulates within the torus instead of carrying energy irreversibly away from it. The proposed configuration therefore represents a stationary electromagnetic object rather than a freely propagating wave.

The previous analysis focused on the dynamics of an individual toroidal cell. It showed that a localized electromagnetic structure may remain stable through the periodic exchange of electric and magnetic energy and through the oscillatory redistribution of electromagnetic stresses. However, an important question remained unanswered. The circumference of an individual toroidal cell may be insufficient to accommodate a complete electromagnetic phase cycle required for a self-consistent standing configuration.

This observation motivates the central hypothesis of the present work. Instead of assuming that every toroidal cell forms an independent electromagnetic resonator, we consider the possibility that several neighboring cells become phase-coherent and together constitute a single larger electromagnetic structure. In such a configuration, the phase-closure condition is satisfied only after the electromagnetic field has traversed the entire closed chain of cells. The elementary toroidal cell is therefore regarded as a local structural unit, whereas the complete resonant object is the closed multi-cell structure, referred to here as an electromagnetic supertorus.

The formation of such a supertorus naturally introduces two distinct geometrical levels. The first is the local toroidal geometry of each individual cell, which determines the local orientation of the electric field, magnetic field, displacement current, and Poynting vector. The second is the global geometry of the closed chain, which determines the overall phase closure, energy circulation, and coherence of the entire electromagnetic structure.

The existence of a coherent multi-cell configuration also changes the interpretation of several physical quantities. Instead of assigning properties such as resonance, phase closure, or effective electric charge to an individual toroidal cell, these quantities may become global properties of the complete supertorus. Consequently, only the entire coherent structure, rather than its individual constituents, is considered a candidate for a stable localized electromagnetic object.

The objective of this paper is therefore threefold. First, we formulate the geometrical and phase conditions required for coherent coupling of multiple toroidal cells into a closed electromagnetic supertorus. Second, we investigate how these conditions reduce the number of independent parameters describing the structure. Finally, assuming that a stable supertorus could represent a localized electromagnetic particle, we examine how the experimentally known properties of the electron may be used to constrain the remaining free parameters of the model. The purpose of this comparison is not to identify the electron with the proposed structure, but to determine whether the model can reproduce the characteristic scales associated with a stable charged particle.

## 2. Electromagnetic Structure of an Individual Toroidal Cell

The present work builds upon the previously proposed stationary electromagnetic toroidal cell and therefore summarizes only those properties that are directly relevant to the development of the multi-cell model.

An individual toroidal cell is considered to be a localized electromagnetic configuration in which the electric and magnetic fields remain mutually orthogonal throughout the oscillation cycle. The electric field is predominantly oriented normal to the toroidal surface, whereas the magnetic field follows the major toroidal circumference. Their temporal evolution is coupled through Maxwell's equations, giving rise to a displacement current that periodically converts electric energy into magnetic energy and back again.

Within the local orthogonal coordinate system of the toroidal cell,

$$\mathbf{E} = E_n\,\hat{\mathbf{n}},$$

$$\mathbf{B} = B_\varphi\,\hat{\boldsymbol{\varphi}},$$

and the displacement current density is

$$\mathbf{J}_{\mathrm{D}} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}.$$

The local electromagnetic energy flow is described by the Poynting vector,

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E} \times \mathbf{B},$$

which is directed approximately along the poloidal direction of the toroidal tube. Rather than transporting energy away from the structure, the Poynting vector participates in the internal redistribution of electromagnetic energy required for dynamic equilibrium.

Unlike a freely propagating electromagnetic wave, the stationary toroidal cell does not exhibit a persistent outward energy flux. Instead, the electric and magnetic energies oscillate periodically while the electromagnetic stresses remain approximately balanced over one oscillation period. The toroidal geometry therefore acts as a confined electromagnetic resonator rather than as a radiating source.

The local toroidal cell is regarded as the fundamental building block of the present model. However, the principal assumption developed in this paper is that an individual cell need not constitute a complete resonant object. Instead, several neighboring cells may become phase-coherent and together form a larger closed electromagnetic structure. Consequently, the electromagnetic properties discussed in this section should be interpreted as local properties of each constituent cell, while resonance, phase closure, and possibly effective electric charge are investigated as global properties of the complete supertorus.

## 3. Electric-Field Asymmetry and the Effective Charge of a Toroidal Cell

A stationary toroidal electromagnetic cell contains an electric field that oscillates periodically while remaining approximately normal to the toroidal surface. During one half of the oscillation period the field is directed predominantly outward from the toroidal surface, whereas during the following half-period its direction is reversed. In an ideal plane wave, the two half-periods are spatially equivalent and therefore produce no net time-averaged electric field. In a toroidal geometry, however, the two field configurations need not be geometrically equivalent.

The outer half of the toroidal surface is convex with respect to the surrounding space. Electric field lines directed outward from this region can expand freely into the exterior volume. In contrast, the inner half of the torus is concave. Field components directed toward the central opening encounter contributions originating from opposite sides of the toroidal ring. Owing to the rotational symmetry of the torus, these inward-directed components tend to compensate each other.

For an ideal axisymmetric torus, the electric field on opposite azimuthal positions satisfies approximately

$$\mathbf{E}(\varphi+\pi) \approx -\mathbf{E}(\varphi),$$

which leads to

$$\int_0^{2\pi} \mathbf{E}_{\text{inner}}(\varphi)\, d\varphi \approx 0.$$

This cancellation refers to the vector sum of the inward-directed field components. It does not imply that the electromagnetic energy associated with the electric field disappears; rather, the field energy remains stored locally while its net contribution to the external field is strongly reduced.

Consequently, the outward- and inward-directed half-periods need not contribute equally to the electric field observed outside the toroidal cell. To describe this asymmetry, we introduce a dimensionless cancellation factor

$$0 \leq \eta \leq 1,$$

where η=1 corresponds to equal contributions of both half-periods and η=0 represents complete cancellation of the inward-directed contribution.

The time-averaged external electric field may then be written in the phenomenological form

$$\overline{\mathbf{E}}_{\text{ext}} = \sigma \frac{E_0}{\pi}(1-\eta)\,\hat{\mathbf{r}},$$

where

$$\sigma = \pm 1$$

denotes the orientation, or chirality, of the electromagnetic structure.

The quantity that characterizes the interaction of the toroidal cell with distant objects is not the local electric field itself but the total electric flux through a closed surface surrounding the structure. Accordingly, the effective electric charge is defined by Gauss's law as

$$Q_{\text{eff}} = \varepsilon_0 \oint_\Sigma \overline{\mathbf{E}}_{\text{ext}} \cdot d\mathbf{A}.$$

If the external field approaches spherical symmetry at sufficiently large distances,

$$\overline{\mathbf{E}}_{\text{ext}}(r) = \frac{Q_{\text{eff}}}{4\pi\varepsilon_0 r^2}\hat{\mathbf{r}},$$

the toroidal cell would interact with external electromagnetic fields in the same manner as an object carrying an electric charge.

At this stage, the proposed mechanism should be regarded as a geometrical hypothesis rather than a complete derivation. The local asymmetry of the electric field suggests a possible origin of an effective external field, but it does not by itself establish a non-zero electric flux. Whether the resulting electromagnetic configuration satisfies Maxwell's equations globally and produces a finite effective charge requires analysis of the complete multi-cell structure developed in the following sections.

## 4. Phase Closure in a Single Toroidal Cell

A localized electromagnetic configuration can remain periodic only if its fields return to the same amplitude, orientation, and phase after completing a closed path. For an electromagnetic field propagating along a closed curve Γ, this requirement can be expressed as

$$\oint_\Gamma k(s)\, ds = 2\pi m, \qquad m \in \mathbb{Z},$$

where k(s) is the local wave number and m is the integer mode number. The condition ensures that the field joins continuously to itself after one complete circuit.

If the effective wave number is approximately constant along the path, the closure condition reduces to

$$kL = 2\pi m,$$

where L is the effective length of the closed electromagnetic path. Since

$$k = \frac{2\pi}{\lambda},$$

the same condition may be written as

$$L = m\lambda.$$

Thus, a closed resonant path must contain an integer number of wavelengths. For the lowest nontrivial mode,

$$m = 1,$$

the effective path length is equal to one wavelength:

$$L = \lambda.$$

The integer m is a property of the complete closed field configuration. It counts the total phase accumulation around the closed path and should not be interpreted merely as the number of geometrical turns of a field line. A geometrically complicated path may still correspond to m=1 if the total phase change along that path is 2π.

For an individual toroidal cell, the effective phase path may follow either the poloidal circumference of the tube, the major toroidal circumference, or a combined helical trajectory, depending on the actual distribution of the electric and magnetic fields. We therefore denote the effective path length of one cell by

$$L_0 = \kappa_0 a,$$

where a is the minor radius of the cell and κ0 is a dimensionless geometrical factor determined by the shape of the phase trajectory. For a simple poloidal path,

$$\kappa_0 \approx 2\pi,$$

whereas a helical or otherwise deformed path generally has a larger value.

A single cell can form an independent resonant object only if

$$kL_0 = 2\pi m.$$

In particular, the fundamental mode requires

$$L_0 = \lambda.$$

However, the characteristic dimensions of the cell may be smaller than the wavelength associated with its temporal oscillation. In that case,

$$L_0 < \lambda$$

and therefore

$$kL_0 < 2\pi.$$

The phase accumulated within one cell is then

$$\Delta\phi_0 = kL_0,$$

with

$$0 < \Delta\phi_0 < 2\pi.$$

Such a cell does not contain a complete electromagnetic phase cycle and cannot, by itself, satisfy the global periodicity condition. This does not necessarily imply that the local electromagnetic configuration must disappear. It means only that the cell cannot be treated as an isolated resonator with its own integer mode number.

It is important to distinguish between the local phase increment and the global mode number. The quantity

$$\frac{\Delta\phi_0}{2\pi}$$

may be smaller than unity, but it should not be interpreted as a fractional mode number belonging to the individual cell. The integer mode number is defined only for a complete closed trajectory. A single cell contributes a fraction of the total phase accumulation, whereas the complete coherent structure must satisfy

$$\Delta\phi_{\text{total}} = 2\pi m.$$

If N identical cells are connected with negligible additional phase shifts, their total phase accumulation is

$$\Delta\phi_{\text{total}} = N\Delta\phi_0 = NkL_0.$$

The global closure condition then becomes

$$NkL_0 = 2\pi m.$$

For the fundamental global mode,

$$m = 1,$$

this gives

$$NL_0 = \lambda.$$

Consequently, an individual toroidal cell may contain only the fraction

$$\Delta\phi_0 = \frac{2\pi}{N}$$

of the complete fundamental cycle. The smallest independently resonant object is then not one cell but the entire coherent chain of N cells.

The phase-closure requirement therefore provides the principal motivation for extending the single-cell model. A toroidal cell may remain a meaningful local field configuration even when it is too small to support a complete resonant cycle. Several such cells can potentially satisfy the periodicity condition collectively, provided that the electromagnetic fields remain continuous and phase-coherent at their interfaces. The formation and closure of such a multi-cell structure are examined in the following sections

## 5. Formation of a Coherent Chain of Toroidal Cells

If an individual toroidal cell contributes only a fraction of the phase required for a complete electromagnetic cycle, several cells must become mutually coherent in order to form a resonant structure. The cells must therefore not behave as independent oscillators. Their electric and magnetic fields must remain continuously connected, with fixed phase relations between neighboring cells.

Let the j-th toroidal cell contribute the phase increment

$$\Delta\phi_j = \int_{\Gamma_j} k(s)\, ds,$$

where Γj denotes the effective electromagnetic path through that cell. For a chain containing N cells, the total phase accumulation is

$$\Delta\phi_{\text{chain}} = \sum_{j=1}^{N} \Delta\phi_j.$$

If the cells are identical,

$$\Delta\phi_j = \Delta\phi_0,$$

and therefore

$$\Delta\phi_{\text{chain}} = N\Delta\phi_0.$$

A coherent chain is formed only if the phase difference between neighboring cells remains constant in time. If Φj(t) denotes the local phase of the j-th cell, then

$$\Phi_{j+1}(t) - \Phi_j(t) = \Delta\phi_0.$$

The absolute phase may vary periodically, but the relative phase must remain fixed. This phase locking allows the cells to act as different segments of one extended electromagnetic mode.

Phase coherence alone is not sufficient. The electromagnetic fields must also join continuously across the interfaces between neighboring cells. In an idealized chain, the boundary conditions may be expressed as

$$\mathbf{E}_j^{\mathrm{out}} = \mathbf{E}_{j+1}^{\mathrm{in}},$$
$$\mathbf{B}_j^{\mathrm{out}} = \mathbf{B}_{j+1}^{\mathrm{in}}.$$

The superscripts "out" and "in" denote the field values on opposite sides of the interface. These relations represent continuity of the field itself. In a more complete description, the relevant tangential and normal components must satisfy the standard electromagnetic boundary conditions.

Because the electric field oscillates in time, continuity of the displacement current is equally important. The displacement-current density is

$$\mathbf{J}_{\mathrm{D}} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}.$$

At the interface between two cells, the coherent structure therefore requires approximately

$$\mathbf{J}_{\mathrm{D},j}^{\mathrm{out}} = \mathbf{J}_{\mathrm{D},j+1}^{\mathrm{in}}.$$

A discontinuity in the displacement current would imply accumulation of effective charge at the interface or the excitation of additional field components. In the ideal coherent chain considered here, no such accumulation is assumed. The displacement current is instead regarded as one continuous oscillatory path extending through the entire chain.

The magnetic field must likewise be oriented so that it supports the continuation of the local electromagnetic dynamics from one cell to the next. If the local electric field is approximately normal to the toroidal surface and the magnetic field follows the local toroidal direction, the orientation of the local basis changes along the chain. The field vectors must therefore rotate continuously together with the geometry of the cells.

For neighboring cells, this geometrical matching may be written schematically as

$$\mathbf{E}_{j+1} = \mathcal{R}_j \mathbf{E}_j,$$
$$\mathbf{B}_{j+1} = \mathcal{R}_j \mathbf{B}_j,$$

where Rj is the rotation that maps the local coordinate system of the j-th cell onto that of the next cell. The same transformation applies to the displacement current and the Poynting vector.

This distinction between phase continuity and vector continuity is important. Two cells may oscillate with the correct scalar phase difference while their field vectors remain incorrectly oriented. Such cells would not constitute one continuous electromagnetic structure. Coherence therefore requires both

$$\Phi_{j+1} - \Phi_j = \Delta\phi_0$$

and consistent geometrical transport of the field orientation.

The local Poynting vector is

$$\mathbf{S}_j = \frac{1}{\mu_0} \mathbf{E}_j \times \mathbf{B}_j.$$

For a coherent chain, the energy flow leaving one cell must enter the neighboring cell:

$$\mathbf{S}_j^{\mathrm{out}} \cdot \hat{\mathbf{n}}_j = \mathbf{S}_{j+1}^{\mathrm{in}} \cdot \hat{\mathbf{n}}_{j+1},$$

where the normals are chosen consistently at the interface. This condition prevents systematic energy accumulation or depletion in any individual cell.

In an ideal stationary chain, the time-averaged energy of each cell remains constant,

$$\left\langle \frac{dU_j}{dt} \right\rangle = 0.$$

Instantaneously, however, energy may pass between neighboring cells. The individual cell is therefore not necessarily energetically closed. It forms part of a larger system in which electromagnetic energy is redistributed continuously while the total energy remains constant.

The total electromagnetic energy of the chain is

$$U_{\text{chain}} = \sum_{j=1}^{N} U_j + U_{\text{coupling}},$$

where Ucoupling represents the field energy in the transition regions between neighboring cells. For weakly deformed and strongly overlapping cells, this coupling energy may be small compared with the energy stored within the cells. In general, however, it cannot be neglected and must ultimately be obtained from the continuous field solution.

A chain of toroidal cells should therefore not be interpreted as a mechanical assembly of separate rings placed next to one another. The division into cells is a geometrical description of a continuous electromagnetic field. The boundaries between cells are not physical surfaces but convenient reference sections along the extended structure.

This interpretation also affects the electric properties of the chain. Any effective electric field associated with an individual cell cannot simply be assigned independently to each unit and added as a set of isolated charges. The external field depends on the coherent superposition of all local electric-field contributions, including those in the coupling regions. Consequently, the electric charge, if generated by the complete configuration, is expected to be a collective property of the coherent mode rather than the sum of independent cell charges.

The coherent chain may remain open only as an intermediate configuration. At its two ends, the phase, displacement current, and energy flow would terminate or require interaction with an external field. A stationary isolated structure therefore requires the chain to close upon itself. The geometrical and electromagnetic conditions for this final closure lead to the formation of the supertorus considered in the next section

## 6. Closure of the Chain into an Electromagnetic Supertorus

A coherent chain of toroidal cells constitutes an extended electromagnetic structure. However, an open chain still possesses two terminal ends at which the electromagnetic phase, displacement current, and energy flow would necessarily terminate or interact with the surrounding field. Such a configuration cannot represent a stationary isolated object. A self-contained electromagnetic structure therefore requires the chain to close upon itself.

The closure is achieved by connecting the last toroidal cell to the first, thereby forming a larger toroidal ring referred to in this work as an **electromagnetic supertorus**. The resulting structure possesses two distinct geometrical levels. Each individual cell retains its local toroidal geometry, while the chain itself follows a second, larger toroidal trajectory. The supertorus is therefore characterized by a hierarchy of two closed geometries rather than by a single toroidal surface.

This construction introduces two independent angular coordinates. The local coordinate,

$$\theta,$$

describes the position around the minor circumference of each toroidal cell, whereas the global coordinate,

$$\psi,$$

describes the position of the cell along the major circumference of the supertorus.

The electromagnetic field is therefore naturally represented as a function of both variables,

$$\mathbf{E} = \mathbf{E}(\theta, \psi, t),$$

$$\mathbf{B} = \mathbf{B}(\theta, \psi, t).$$

The local oscillation within each cell and the global progression around the supertorus together determine the complete phase of the electromagnetic structure.

The total phase accumulated along the entire closed path is

$$\Delta\phi_{\text{total}} = \sum_{j=1}^{N} \Delta\phi_j,$$

which, for identical cells, becomes

$$\Delta\phi_{\text{total}} = N\Delta\phi_0.$$

A stationary supertorus requires the global phase closure condition

$$\Delta\phi_{\text{total}} = 2\pi m,$$

or equivalently,

$$N\Delta\phi_0 = 2\pi m.$$

Thus, the integer mode number belongs to the complete supertorus rather than to its individual cells.

The closure of the chain also removes the distinction between the beginning and the end of the electromagnetic path. Every cell has two neighboring cells, and the displacement current forms one continuous closed loop extending through the entire structure. Likewise, the Poynting vector no longer transports energy toward terminal boundaries but circulates continuously around the complete supertorus.

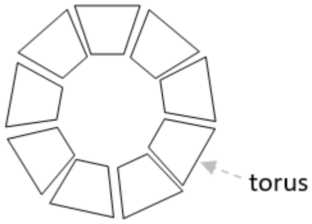


**Figure 1.** *Conceptual geometry of the proposed electromagnetic supertorus. Each small toroidal cell represents a local electromagnetic oscillation, while the complete closed chain forms the globally phase-coherent resonator. The local coordinate ϑ describes the internal toroidal dynamics of each cell, whereas the global coordinate ψ describes the position along the supertorus. Observable properties are attributed to the complete coherent structure rather than to individual cells.*

The local electromagnetic dynamics remain essentially unchanged. Within each cell, the electric and magnetic fields continue to exchange energy through the displacement current exactly as described in the previous sections. The global closure introduces an additional level of organization by imposing coherence among all cells simultaneously. Consequently, local oscillations and global phase evolution become inseparable aspects of the same electromagnetic mode.

The supertorus may therefore be regarded as a resonator possessing both local and global resonance conditions. The local geometry determines the electromagnetic field distribution inside each toroidal cell, whereas the global geometry determines whether the complete structure satisfies the phase-closure requirement necessary for a stationary electromagnetic configuration.

An additional consequence of the global closure concerns the electric properties of the structure. Since the electromagnetic field forms one continuous closed configuration, any effective external electric field cannot be attributed independently to individual cells.

Instead, the external field results from the coherent superposition of contributions from the entire supertorus. If an effective electric charge emerges, it should therefore be regarded as a collective property of the complete electromagnetic mode.

The same conclusion applies to the electromagnetic energy. The total energy of the supertorus is

$$U_{\text{super}} = \sum_{j=1}^{N} U_j + U_{\text{coupling}},$$

where the second term represents the energy associated with the electromagnetic coupling between neighboring cells. The supertorus is therefore not merely a collection of identical resonators but a single continuous electromagnetic object whose properties arise from the collective behavior of all constituent cells.

The transition from an open chain to a closed supertorus completes the geometrical construction of the proposed model. The remaining question is whether such a multi-cell configuration can satisfy Maxwell's equations as a continuous electromagnetic field while maintaining the required continuity of the electric field, magnetic field, displacement current, and energy flow. This question is addressed in the following section.

## 7. Global Electric Field and Charge of the Supertorus

The preceding sections considered the electromagnetic properties of individual toroidal cells and their coherent coupling into a closed supertorus. The closure of the structure introduces an important distinction between local and global electromagnetic behavior. While the electric field within each cell oscillates periodically with zero average over one complete cycle, the coherent superposition of many cells may produce a non-vanishing electric field outside the complete structure.

The essential point is that the electric field of the supertorus is determined by the global electromagnetic configuration rather than by the field of any individual cell. Each cell contributes only a local segment of the total field, whereas the external field results from the coherent superposition of all contributions distributed around the closed supertorus.

Within each toroidal cell, the electric field alternates between outward- and inward-directed configurations. Because of the toroidal geometry, these two configurations are not geometrically equivalent. Outward-directed field lines can expand freely into the surrounding space, whereas inward-directed field components are confined within the interior region of the supertorus and experience substantial mutual cancellation owing to the rotational symmetry of the structure.

Consequently, the coherent superposition of all cells need not preserve the symmetry between the two half-periods. The local asymmetry discussed in Section 3 is reinforced by the global geometry of the closed supertorus. The resulting external field is therefore regarded as a collective property of the entire electromagnetic mode rather than the sum of independent fields generated by individual cells.

To describe this effect phenomenologically, we write the time-averaged external electric field as

$$\overline{\mathbf{E}}_{\text{ext}} = \sigma\, \alpha\, E_0\, \hat{\mathbf{r}},$$

where $E_0$ denotes the characteristic electric-field amplitude inside the structure,

$$\sigma = \pm 1$$

represents the two possible chiralities of the coherent mode, and

$$0 \leq \alpha \leq 1$$

is a dimensionless geometrical factor describing the efficiency with which the internal electric field contributes to the external field. The parameter α depends on the complete geometry of the supertorus and cannot be determined from an isolated cell.

If the external field approaches spherical symmetry sufficiently far from the structure, Gauss's law defines the effective electric charge,

$$Q_{\mathrm{eff}} = \varepsilon_0 \oint_{\Sigma} \mathbf{\overline{E}}_{\mathrm{ext}} \cdot d\mathbf{A}.$$

At large distances, the corresponding field becomes

$$\mathbf{\overline{E}}_{\mathrm{ext}}(r) = \frac{Q_{\mathrm{eff}}}{4\pi\varepsilon_0 r^2}\hat{\mathbf{r}},$$

which is identical in form to the electric field of a point charge. The internal electromagnetic structure would then be observable externally only through the value of the effective charge and not through its detailed geometry.

An important consequence of this interpretation is that the effective charge is associated with the global coherent mode rather than with its constituent cells. Formally,

$$Q_{\mathrm{eff}} \neq \sum_{j=1}^{N} Q_j,$$

because individual cells are not regarded as isolated charged objects. Instead,

$$Q_{\mathrm{eff}} = Q(m, \sigma, \alpha),$$

where the effective charge depends on the global resonance mode m, the chirality σ, and the geometrical coupling factor α. Thus, charge becomes a property of the complete electromagnetic configuration.

The existence of two opposite chiralities naturally permits two opposite orientations of the external electric field. If the geometrical factor α remains unchanged while the chirality changes sign,

$$Q_{\mathrm{eff}}(\sigma) = -Q_{\mathrm{eff}}(-\sigma).$$

The model therefore predicts two configurations possessing equal magnitudes of the effective charge but opposite polarity.

It should be emphasized that the present treatment is phenomenological. The above equations do not constitute a derivation of electric charge from Maxwell's equations alone. Rather, they provide a mathematical framework for describing how a globally coherent electromagnetic configuration could exhibit an effective external electric field if the complete solution of Maxwell's equations indeed possesses the required asymmetry.

The decisive theoretical question is therefore whether the continuous Maxwell solution for the complete supertorus produces a finite electric flux through a closed surface surrounding the structure. A positive result would establish the effective charge directly from the field configuration. A negative result would indicate that an additional physical mechanism is required. The present model should therefore be regarded as a hypothesis whose validity ultimately depends on the existence of such a globally self-consistent electromagnetic solution.

## 8. Local and Global Energy Circulation

The electromagnetic supertorus possesses two distinct levels of energy circulation that arise naturally from its hierarchical geometry. The first level corresponds to the periodic exchange of electric and magnetic energy within each individual toroidal cell. The second level corresponds to the transport of electromagnetic energy around the complete supertorus through the coherent coupling of all cells.

Within an individual cell, the electric and magnetic fields oscillate continuously while remaining mutually orthogonal. Their interaction is governed by Maxwell's equations through the displacement current,

$$\mathbf{J}_{\mathrm{D}} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t},$$

which periodically converts electric energy into magnetic energy and back again. The local electromagnetic energy density is

$$u = \frac{1}{2}\left(\varepsilon_0 E^2 + \frac{B^2}{\mu_0}\right).$$

Although the electric and magnetic contributions vary during the oscillation cycle, the total local energy remains approximately constant,

$$\left\langle \frac{du}{dt} \right\rangle = 0,$$

where the brackets denote the average over one oscillation period.

The associated local energy transport is described by the Poynting vector,

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E} \times \mathbf{B}.$$

As discussed previously, the Poynting vector is directed predominantly along the poloidal direction of the toroidal tube. Consequently, the electromagnetic energy circulates around the cross-section of each cell rather than propagating away from the structure.

The coherent coupling of neighboring cells introduces a second level of energy transport. Since the displacement current and the electromagnetic fields remain continuous across cell boundaries, the local Poynting flow also becomes continuous. Electromagnetic energy therefore passes smoothly from one toroidal cell into the next.

The total energy flow is thus described by a continuous vector field extending throughout the entire chain,

$$\mathbf{S} = \mathbf{S}(\theta, \psi, t),$$

where the local coordinate θ describes circulation inside each cell and the global coordinate ψ describes the position along the supertorus.

After closure of the chain, the global Poynting flow becomes a closed trajectory. Electromagnetic energy no longer encounters terminal boundaries but circulates continuously around the complete supertorus. The total energy flux therefore satisfies the periodicity condition

$$\mathbf{S}(\psi + 2\pi) = \mathbf{S}(\psi).$$

The local circulation and the global circulation are not independent processes. The local oscillation inside every cell continuously feeds the global energy transport, while the global coherent mode maintains the phase relations required for the stability of the local oscillations. The two processes therefore form a self-consistent electromagnetic feedback system.

The total electromagnetic energy of the supertorus is

$$U = \int_V u \, dV,$$

where the integration extends over the entire electromagnetic structure. Since the supertorus is assumed to be stationary,

$$\frac{dU}{dt} = 0.$$

This condition does not imply the absence of internal dynamics. On the contrary, electric and magnetic energies are continuously exchanged locally, while electromagnetic energy simultaneously circulates globally around the supertorus. The stationary character of the structure therefore results from dynamic equilibrium rather than from static fields.

An important distinction should be made between energy transport and energy radiation. A non-zero Poynting vector does not necessarily imply that electromagnetic energy leaves the structure. In the present model, the Poynting vector follows closed trajectories. The divergence of the time-averaged energy flow therefore vanishes,

$$\nabla \cdot \langle \mathbf{S} \rangle = 0,$$

indicating that electromagnetic energy is redistributed internally rather than emitted into the surrounding space.

The two levels of circulation may therefore be summarized as follows.

The local circulation maintains the periodic exchange between electric and magnetic energy within each toroidal cell and stabilizes the local electromagnetic configuration.

The global circulation transports electromagnetic energy coherently through all cells and maintains the phase closure of the complete supertorus.

Together, these two coupled processes constitute the dynamic mechanism by which the electromagnetic supertorus preserves both its local field configuration and its global coherence.

The existence of two simultaneous circulation scales represents one of the characteristic features of the proposed model. The local toroidal circulation determines the internal dynamics of each constituent cell, whereas the global circulation transforms the collection of cells into a single coherent electromagnetic object. The following section examines whether such a two-level electromagnetic configuration can satisfy the continuity conditions imposed by Maxwell's equations throughout the entire supertorus.

## 9. Maxwell Conditions for the Multi-Cell Structure

The preceding sections proposed a geometrical model consisting of coherently coupled toroidal cells that form a closed electromagnetic supertorus. The physical validity of such a configuration depends entirely on whether it can exist as a continuous solution of Maxwell's equations. The present section therefore formulates the necessary electromagnetic conditions that any stationary multi-cell structure must satisfy.

Throughout the supertorus, the electric and magnetic fields are assumed to obey the vacuum Maxwell equations,

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0},$$

$$\nabla \cdot \mathbf{B} = 0,$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t},$$

$$\nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}.$$

No material medium is introduced. The proposed structure is therefore interpreted entirely as a self-organized electromagnetic field.

The first requirement is field continuity. Since neighboring toroidal cells represent adjacent regions of one continuous electromagnetic field, the electric and magnetic fields must remain continuous across their interfaces. In the absence of singular surface sources,

$$\mathbf{E}(\mathbf{r}) \in C^0,$$

$$\mathbf{B}(\mathbf{r}) \in C^0,$$

throughout the complete supertorus.

The second requirement is the continuity of the displacement current,

$$\mathbf{J}_{\mathrm{D}} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}.$$

The displacement current must form one uninterrupted closed loop through the entire structure. Local accumulation of charge at the interfaces would destroy the assumed stationary oscillation.

The third requirement concerns magnetic continuity. Because

$$\nabla \cdot \mathbf{B} = 0,$$

magnetic field lines cannot begin or terminate within the structure. The magnetic field must therefore form continuous closed trajectories extending through all toroidal cells.

The fourth requirement is the continuity of electromagnetic energy transport. The Poynting vector,

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E} \times \mathbf{B},$$

must not exhibit discontinuous jumps between neighboring cells. Instead, the local and global energy circulation described in the previous section must constitute one continuous energy-flow field satisfying

$$\nabla \cdot \langle \mathbf{S} \rangle = 0$$

for the stationary configuration.

The fifth requirement concerns phase continuity. Since the complete supertorus represents one coherent electromagnetic mode, the phase must remain single-valued around every closed trajectory,

$$\oint_\Gamma k(s)\, ds = 2\pi m, \qquad m \in \mathbb{Z}.$$

Any discontinuity of the phase would necessarily introduce singularities into the electric and magnetic fields and destroy the global resonance.

An additional requirement follows from the hierarchical geometry introduced in the preceding sections. The electromagnetic field depends simultaneously on the local coordinate of each toroidal cell and on the global coordinate of the supertorus,

$$\mathbf{E} = \mathbf{E}(\theta, \psi, t),$$

$$\mathbf{B} = \mathbf{B}(\theta, \psi, t).$$

Consequently, the derivatives appearing in Maxwell's equations contain both local and global spatial contributions. The complete field solution must therefore remain differentiable with respect to both coordinates while preserving continuity across the entire structure.

The effective electric charge discussed in Section 7 introduces a further consistency condition. If the supertorus exhibits a non-zero electric flux through a closed surface,

$$Q_{\text{eff}} = \varepsilon_0 \oint \mathbf{E} \cdot d\mathbf{A},$$

then this flux must emerge naturally from the continuous electromagnetic solution. It cannot be introduced as an independent source term without violating the self-contained character of the proposed model.

Accordingly, the principal theoretical challenge is to determine whether Maxwell's equations admit a continuous, finite-energy solution satisfying simultaneously:

- continuity of the electric field,
- continuity of the magnetic field,
- continuity of the displacement current,
- continuity of the Poynting flow,
- global phase closure,
- finite total electromagnetic energy,
- and, if present, a non-zero effective electric flux.

The present work does not claim that such a solution has already been obtained. Rather, these conditions define the mathematical criteria that any future analytical or numerical solution of the proposed multi-cell supertorus must satisfy. If no such solution exists, the proposed model must be regarded as incomplete. Conversely, the existence of a self-consistent solution would provide a strong indication that a stationary electromagnetic structure of the proposed type is compatible with Maxwell's equations.

The role of the present model is therefore not to replace Maxwell's equations but to explore whether Maxwell's equations themselves admit a richer class of stationary vacuum solutions than those commonly considered.

## 10. Reduction of the Independent Parameters

The construction presented in the preceding sections introduces several geometrical and electromagnetic quantities describing the multi-cell supertorus. At first sight, these quantities appear to constitute a large number of independent parameters. However, the continuity conditions imposed by Maxwell's equations, together with the requirements of phase closure and energy conservation, substantially reduce the number of degrees of freedom.

The principal geometrical quantities are the major radius of the supertorus,

**R,**

the minor radius of each toroidal cell,

**a,**

and the number of cells,

**N.**

The principal electromagnetic quantities are the characteristic electric and magnetic field amplitudes,

$$E_0, \qquad B_0,$$

together with the oscillation frequency,

**ω,**

and the geometrical coupling parameter,

**α,**

introduced in Section 7.

If these quantities were independent, the model would possess considerable freedom, making comparison with physical particles difficult. A physically meaningful electromagnetic structure should instead be determined by a relatively small number of independent parameters.

The first reduction follows directly from the propagation of electromagnetic fields in vacuum. The electric and magnetic amplitudes are related through

$$E_0 = cB_0,$$

so that only one field amplitude is independent.

The second reduction arises from the frequency–wavelength relation,

$$\lambda = \frac{2\pi c}{\omega},$$

which determines the characteristic wavelength once the oscillation frequency has been specified.

The third reduction follows from the phase-closure condition of the complete supertorus,

$$N\Delta\phi_0 = 2\pi m.$$

For the fundamental mode,

**m=1**

the number of toroidal cells is no longer independent but is constrained by the phase accumulated within each cell,

$$N = \frac{2\pi}{\Delta\phi_0}.$$

Consequently, the global geometry and the local electromagnetic phase become mutually dependent.

The fourth reduction results from the geometrical closure of the supertorus. The total path length,

$$L_{\text{total}},$$

is simultaneously determined by the number of cells and by the major radius,

$$L_{\text{total}} = NL_0 = 2\pi R_{\text{eff}},$$

where $R_{\text{eff}}$ denotes the effective radius of the global phase trajectory. Thus, the major radius cannot be selected independently once the local geometry and the number of cells have been fixed.

The electromagnetic energy also imposes an important constraint. The total energy,

$$U = \int_V \frac{1}{2}\left(\varepsilon_0 E^2 + \frac{B^2}{\mu_0}\right) dV,$$

depends simultaneously on the field amplitude and on the geometrical dimensions. For a prescribed total energy, these quantities become mutually constrained rather than independent.

The geometrical coupling parameter,

$$\alpha,$$

is likewise not expected to be freely adjustable. In the present model, α represents the efficiency with which the complete electromagnetic geometry generates the external electric field. Since this geometry is itself determined by the continuous Maxwell solution, the value of α should ultimately emerge from the field configuration rather than being introduced as an arbitrary constant.

These considerations suggest that the apparent complexity of the model is substantially reduced once the physical consistency conditions are imposed. Instead of an unrestricted collection of geometrical and electromagnetic quantities, the stationary supertorus is expected to belong to a comparatively small family of self-consistent solutions.

In the ideal case, the complete configuration may be characterized by only a few independent physical parameters, while all remaining quantities follow from Maxwell's equations, the phase-closure condition, and the requirement of finite total energy.

The present work does not determine the final number of independent parameters. Rather, it establishes the framework within which such a reduction should occur. The actual reduction can only be completed after solving the continuous electromagnetic field equations for the entire supertorus.

The importance of this reduction extends beyond mathematical simplicity. A model possessing only a few independent parameters becomes experimentally testable because its observable properties are no longer freely adjustable. If the proposed electromagnetic supertorus is to provide a realistic description of elementary particles, its geometry, field amplitudes, oscillation frequency, and effective charge must ultimately be determined by a small set of self-consistent physical parameters rather than by arbitrary choices.

## 11. Inverse Constraints from the Electron

The preceding sections developed a general model of a stationary electromagnetic supertorus without reference to any particular elementary particle. The purpose of the present section is to reverse the direction of the analysis. Instead of selecting geometrical and electromagnetic parameters arbitrarily, we begin with the experimentally established properties of the electron and examine the constraints they impose on the proposed electromagnetic structure.

The electron is characterized by several accurately measured physical quantities, including its electric charge,

$$e,$$

its rest energy,

$$m_e c^2,$$

its intrinsic magnetic moment,

$$\mu_e,$$

and its intrinsic angular momentum (spin),

$$S = \frac{\hbar}{2}.$$

If the proposed supertorus is to represent an electron, these experimentally observed quantities cannot be regarded as adjustable parameters. Instead, they become boundary conditions that constrain the permissible electromagnetic solutions.

The first constraint concerns the effective electric charge. The external electric field generated by the complete supertorus must reproduce the observed elementary charge,

$$Q_{\text{eff}} = \pm e.$$

Consequently, the geometrical coupling parameter introduced previously,

$$\alpha,$$

cannot be arbitrary but must assume the value required to produce the observed electric flux.

The second constraint concerns the total electromagnetic energy. The stationary field configuration must satisfy

$$U = m_e c^2,$$

where

$$U = \int_V \frac{1}{2}\left(\varepsilon_0 E^2 + \frac{B^2}{\mu_0}\right) dV.$$

Thus, the field amplitudes and geometrical dimensions become mutually constrained by the measured rest energy of the electron.

The third constraint concerns the global resonance condition. The oscillation frequency and the geometrical dimensions cannot be selected independently but must satisfy simultaneously the phase-closure condition and the required total electromagnetic energy. The resulting configuration therefore belongs, if it exists, to a discrete family of coherent stationary modes.

The fourth constraint concerns the magnetic properties of the structure. A closed circulating electromagnetic configuration naturally possesses an associated magnetic moment,

$$\boldsymbol{\mu},$$

whose magnitude and orientation depend on the detailed field distribution. If the model is applicable to the electron, the calculated magnetic moment must reproduce the experimentally observed value.

Likewise, the total angular momentum carried by the electromagnetic field,

$$\mathbf{J} = \int_V \mathbf{r} \times \mathbf{g} \, dV,$$

where

$$\mathbf{g} = \frac{\mathbf{S}}{c^2},$$

denotes the electromagnetic momentum density, must equal the intrinsic angular momentum of the electron.

These constraints illustrate an important conceptual shift. The geometrical model is no longer specified by freely chosen parameters. Instead, the experimentally measured properties of the electron determine which stationary electromagnetic solutions, if any, remain admissible.

The present work does not attempt to calculate these quantities explicitly. Such calculations require a complete solution of Maxwell's equations for the proposed multi-cell supertorus. Nevertheless, the inverse formulation provides a systematic strategy for evaluating the physical relevance of the model.

Rather than asking whether an arbitrary electromagnetic structure resembles an electron, the inverse approach asks whether the unique experimentally measured properties of the electron can all emerge from a single self-consistent stationary electromagnetic configuration. Only if the effective charge, total energy, magnetic moment, spin, and phase coherence are reproduced simultaneously can the proposed model be regarded as a viable candidate for describing the electron.

Although the electron provides the most natural starting point because its properties are known with exceptional precision, the same inverse methodology can be applied to any elementary particle. Each particle would correspond to a different set of experimentally measured boundary conditions, allowing the existence and uniqueness of stationary electromagnetic solutions to be investigated in a systematic manner.

The inverse constraints therefore transform the proposed supertorus from a purely geometrical construction into a quantitatively testable physical hypothesis. Future analytical and numerical investigations should determine whether Maxwell's equations admit stationary vacuum solutions satisfying all of these experimental constraints simultaneously.

## 12. Magnetic Moment, Spin, and Chirality as Tests of the Model

The effective electric charge and the total electromagnetic energy constitute only part of the experimentally observed properties of the electron. Any physically realistic electromagnetic model must also account for its magnetic moment, intrinsic angular momentum, and the existence of two opposite charge states. These quantities therefore provide independent tests of the proposed supertorus model.

The closed circulation of electromagnetic energy naturally implies the existence of a magnetic moment. In the present model, this moment is not introduced as an additional assumption but is expected to emerge from the continuous circulation of the electromagnetic field within the stationary supertorus.

The magnetic moment,

$$\boldsymbol{\mu},$$

is determined by the complete distribution of the electromagnetic field and therefore depends on both the local toroidal circulation and the global circulation around the supertorus. Consequently, it is a collective property of the entire coherent electromagnetic configuration rather than of any individual toroidal cell.

A second observable quantity is the total angular momentum carried by the electromagnetic field. The field momentum density is

$$\mathbf{g} = \frac{\mathbf{S}}{c^2},$$

where

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E} \times \mathbf{B}$$

is the Poynting vector. The total angular momentum is therefore

$$\mathbf{J} = \int_V \mathbf{r} \times \mathbf{g}\, dV.$$

If the proposed stationary supertorus is to represent the electron, the resulting angular momentum must reproduce the experimentally observed intrinsic value,

$$|\mathbf{J}| = \frac{\hbar}{2}.$$

The present work does not evaluate this integral explicitly. Rather, it identifies the angular momentum as one of the principal quantities that any complete electromagnetic solution must reproduce.

An equally important property is the magnetic moment. Since both the magnetic moment and the angular momentum arise from the same electromagnetic field, they cannot be adjusted independently. The field configuration that determines one quantity simultaneously determines the other. This provides a stringent consistency test of the proposed model because both observables are known experimentally with very high precision.

The concept of chirality introduced earlier also acquires a direct physical interpretation. The supertorus admits two possible orientations of the coherent electromagnetic circulation. These two chiral configurations correspond to opposite orientations of the global electromagnetic mode,

$$\sigma = \pm 1.$$

If the remaining geometrical parameters remain unchanged, reversal of the chirality reverses the direction of the external electric field,

$$Q_{\mathrm{eff}}(\sigma) = -Q_{\mathrm{eff}}(-\sigma),$$

while simultaneously reversing the orientation of the magnetic moment,

$$\boldsymbol{\mu}(\sigma) = -\boldsymbol{\mu}(-\sigma).$$

Thus, opposite chiralities naturally generate electromagnetic configurations possessing opposite electric charge and opposite magnetic orientation while preserving the same total electromagnetic energy.

Whether the angular momentum also changes sign under chirality reversal depends on the detailed electromagnetic field solution. This question cannot be answered from geometrical considerations alone and therefore remains an open problem for future analytical and numerical investigation.

The existence of two coherent chiral solutions represents an important qualitative prediction of the proposed model. Rather than introducing positive and negative electric charge as independent physical entities, the model suggests that both may arise from two globally coherent electromagnetic configurations possessing identical geometry but opposite orientation of the electromagnetic circulation.

These considerations lead to three experimentally accessible quantities that provide largely independent tests of the model:

- the effective electric charge,
- the magnetic moment,
- and the total angular momentum.

Agreement with only one of these observables would not be sufficient. A viable stationary electromagnetic solution must reproduce all three simultaneously while remaining consistent with Maxwell's equations, finite total energy, and global phase closure.

The proposed supertorus should therefore be regarded not merely as a geometrical construction but as a predictive physical model. Its validity depends on whether a single self-consistent electromagnetic field configuration can simultaneously account for the electric, magnetic, and dynamical properties observed experimentally for the electron

If future solutions demonstrate that opposite chiralities necessarily produce opposite effective electric flux, chirality would provide a natural electromagnetic mechanism for the existence of opposite charge states.

## 13. Discussion and Open Problems

The present work proposes a geometrical framework in which a stationary electromagnetic field forms a coherent hierarchy of toroidal cells organized into a closed supertorus. The principal objective has not been to introduce new electromagnetic equations but to investigate whether Maxwell's equations may admit a richer class of stationary vacuum solutions than those commonly considered.

The proposed model combines several elements that are usually studied separately. These include local electromagnetic oscillations, coherent phase locking, hierarchical toroidal geometry, continuous circulation of electromagnetic energy, and the possible emergence of an effective external electric field from a globally coherent electromagnetic configuration. Together, these elements define a candidate mechanism by which an extended electromagnetic structure might exhibit particle-like properties.

A central feature of the model is the distinction between local and global organization. Individual toroidal cells are introduced primarily as geometrical elements describing the internal structure of the electromagnetic field. Observable physical properties, including the effective electric charge, total energy, magnetic moment, and angular momentum, are instead regarded as collective properties of the complete supertorus.

An important consequence of this viewpoint is that the model contains comparatively few independent assumptions. Once Maxwell's equations, phase closure, finite energy, and geometrical continuity are imposed, the apparent freedom of the construction is substantially reduced. The experimentally observed properties of the electron then become inverse constraints rather than adjustable parameters.

Despite these encouraging features, the present work remains incomplete in several essential respects.

First, no complete analytical solution of Maxwell's equations has yet been obtained for the proposed multi-cell geometry. The existence of such a solution therefore remains an open mathematical question.

Second, the effective electric charge has been introduced phenomenologically through the global electric flux. Whether a continuous vacuum solution can indeed produce a non-zero external electric field without introducing singular charge sources must be demonstrated explicitly.

Third, the magnetic moment and angular momentum have been identified as natural observables of the model, but neither quantity has yet been calculated from the electromagnetic field. Their quantitative evaluation constitutes an essential test of the proposed structure.

Fourth, the relation between the two chiral solutions and the existence of positive and negative charge remains hypothetical. A rigorous derivation would require the complete electromagnetic solution together with an analysis of its symmetry properties.

Fifth, the stability of the stationary supertorus has not yet been investigated. Even if Maxwell's equations admit such a solution, it remains necessary to determine whether the configuration is dynamically stable under small perturbations or whether it evolves toward a different electromagnetic state.

These open questions naturally define the next stages of the investigation.

The first objective should be the numerical solution of Maxwell's equations in the proposed hierarchical toroidal geometry. Such calculations would establish whether stationary finite-energy solutions satisfying the required continuity conditions actually exist.

If such solutions are found, the second objective would be the calculation of observable quantities including the effective electric charge, magnetic moment, angular momentum, total electromagnetic energy, and characteristic geometrical dimensions.

Only after these quantities have been derived directly from the electromagnetic field can meaningful comparison with the experimentally measured properties of elementary particles be undertaken.

The proposed model is therefore best regarded as a working hypothesis rather than as a completed physical theory. Its principal contribution is the formulation of a mathematically well-defined geometrical problem whose solution, if it exists, can be tested quantitatively against experimental observations.

Regardless of whether the proposed supertorus ultimately proves to describe elementary particles, the underlying mathematical question remains of independent interest: whether Maxwell's equations possess previously unexplored stationary vacuum solutions exhibiting hierarchical electromagnetic organization.

If such solutions exist, they would enlarge the known solution space of classical electromagnetism. If they do not, the present framework will nevertheless have established clear mathematical criteria delimiting the possibilities for stationary self-confined electromagnetic structures in vacuum.

Thus, the value of the present investigation does not depend solely on the correctness of the proposed model but also on the precise formulation of the questions that it raises. In this sense, the work aims to stimulate further analytical, numerical, and experimental studies of coherent electromagnetic structures within the established framework of Maxwellian electrodynamics.

The proposed model should therefore be judged not by the originality of its geometry alone, but by its ability to reproduce measurable physical properties from a single self-consistent electromagnetic solution.

## 14. Conclusions

This work has presented a conceptual framework for describing a stationary electromagnetic structure composed of coherently coupled toroidal cells forming a closed electromagnetic supertorus. The proposed construction remains entirely within the framework of classical vacuum electrodynamics and introduces no modifications to Maxwell's equations. Instead, it explores whether the known equations may admit a class of stationary finite-energy solutions possessing a hierarchical toroidal organization.

The model is based on several interconnected principles: local electromagnetic oscillations, coherent phase locking between neighboring toroidal cells, global phase closure, continuous circulation of displacement current and electromagnetic energy, and the possibility that observable particle properties emerge collectively from the complete electromagnetic configuration rather than from its individual components.

Within this framework, quantities such as effective electric charge, total electromagnetic energy, magnetic moment, and angular momentum are interpreted as global properties of the coherent supertorus. The model further suggests that opposite chiralities of the global electromagnetic circulation may provide a natural mechanism for the existence of opposite charge states, although this hypothesis requires verification through complete solutions of Maxwell's equations.

An important methodological feature of the present work is the use of inverse constraints. Instead of adjusting the parameters of the model to obtain desired particle properties, the experimentally measured characteristics of the electron are treated as boundary conditions that any admissible electromagnetic solution must satisfy. This approach transforms the proposed supertorus from a purely geometrical construction into a quantitatively testable physical hypothesis.

The analysis also identifies the principal mathematical conditions that any stationary solution must fulfill, including field continuity, global phase coherence, finite total energy, continuity of displacement current, and consistency with the vacuum Maxwell equations. These conditions substantially reduce the apparent freedom of the model and define a well-posed problem for future analytical and numerical investigations.

At present, the existence of the proposed stationary electromagnetic supertorus remains an open question. The work does not claim that such solutions have already been obtained. Rather, it establishes a systematic framework for investigating whether Maxwell's equations possess previously unexplored stationary vacuum solutions capable of reproducing the experimentally observed properties of elementary particles.

Future work should therefore focus on solving Maxwell's equations for the proposed multi-cell geometry and determining whether the resulting electromagnetic configurations simultaneously reproduce the effective electric charge, total energy, magnetic moment, angular momentum, and other measurable properties of the electron. Only such quantitative agreement can determine the physical validity of the proposed model.

Regardless of the final outcome, the present study demonstrates that the search for stationary, self-organized electromagnetic structures can be formulated as a precise mathematical problem within classical electrodynamics. Whether these structures ultimately prove to describe elementary particles or simply enlarge the known family of Maxwell solutions, their investigation offers a potentially fruitful direction for future theoretical research.

The central question addressed by this work is therefore not whether Maxwell's equations are complete, but whether their space of physically meaningful stationary solutions has yet been fully explored.