Model of the Wave Structure of Matter and the Fractal Structure of the Universe

Correction dated 23.04.2026:
The revision is largely complete. It has been decided to apply the fractal calculation formula only to a single step—one level down and one level up. The possibility of deriving a more general and simpler formula applicable to transitions between arbitrary levels is not excluded in future work.

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Annotation

This work presents a theoretical model that describes physical reality as a system of interconnected wave processes organized according to the principles of resonance and fractal scalability. Within this framework, elementary particles are treated as stable standing wave configurations in an energy-saturated medium, while interactions between them are interpreted as manifestations of a unified resonant mechanism.

Mass, electric charge, and gravitation are interpreted as characteristics of wave structures arising from the formation of stable resonant states. Fundamental physical constants are considered as parameters that define the conditions of interaction at a given level of description.

Particular attention is given to the fractal organization of physical processes, in which different scale levels are connected through the laws of wave dynamics. It is shown that transitions between levels involve changes in system parameters (scales, frequencies, effective interaction speeds), while preserving their functional relationships.

The work introduces a distinction between the physical structure of a system and its observable representation. It is shown that observed reality is determined by the conditions of resonant interaction and the level of interpretation, which leads to limitations of the observable picture and to a possible dependence of its description on the parameters of the perceptual system.

The proposed model does not contradict existing physical theories but treats them as effective descriptions within their respective scale levels. The work is theoretical in nature and aims to provide a unified interpretative framework linking microscopic and macroscopic phenomena within a common wave-based and fractal perspective.

Keywords: wave structure of matter; resonance; fractal structure; frequency levels; scaling; standing waves; nature of mass; electric charge; gravitation; fundamental constants; interpretation of physical parameters; level of perception; observable reality

Contents

Methodological Principles and Scope of Interpretation of the Model

This section formulates the key principles that define the domain of applicability and the mode of interpretation of the proposed model.

The proposed approach is not intended to replace existing physical theories. Rather, it is considered as an interpretative layer that allows known results to be connected within a unified conceptual framework. All experimentally confirmed relations and mathematical models are preserved and treated as particular cases corresponding to specific levels of description.

Within this approach, physical reality is not viewed as a static geometric structure, but as a system of interrelated processes. In this context, frequency is used as a fundamental characteristic describing the state of the system.

Concepts such as length, time, and mass are not treated as primary. They are introduced as a result of the chosen mode of description, based on the comparison of parameters of wave processes. In particular, time may be interpreted as the counting of repetitions of a cyclic process, while the notion of a dimension arises as a consequence of the need for an unambiguous description of the system's state. The attempt to represent a cyclic process in a linear form leads to a loss of phase information, which requires the introduction of additional coordinates.

As the structure of processes becomes more complex, dependencies arise in which system parameters change in a nonlinear manner. This allows for a representation in which different physical quantities can be considered as manifestations of a unified sequence formed through the scaling of frequency relations. Within this work, the following formal relation is used:

$$\nu_n = \nu_0^{2^n}, n \in N$$

which defines transitions between levels of description and allows physical quantities to be interpreted as different manifestations of a single underlying process.

If we apply this dependence to our physical perception of the World, then:

- ν_0 → base frequency (observer)
- n=1 → first dimension — Time (Order)
- n= second dimension — Space (Structure)

third dimension — Mass (Intensity)

A more detailed exposition of this approach is presented in the work "Emergence of Dimensions and Perception of Fractality" https://zenodo.org/records/19688973 .

Within the model, the speed of light is interpreted as the maximum speed of interaction propagation within a given level. Its invariance is preserved within that level, but does not necessarily extend to comparisons between processes belonging to different levels of description.

Elementary particles are treated as stable wave configurations possessing finite spatial structure. Their representation as point-like objects arises as an effective description associated with observational limitations and the nature of interactions.

The observed physical picture is determined by conditions of resonant coherence and therefore represents a limited projection of a more general dynamics. Processes that are not in resonance with the given level are unlikely to manifest in observation, despite their possible existence. This question requires further investigation.

Fundamental physical constants are interpreted as parameters characterizing a specific level of organization of wave processes. Their values reflect conditions of resonant coherence and are not regarded as universal outside the context of the corresponding level of description.

1. Introduction

Modern fundamental physics has achieved significant success in describing a wide range of phenomena. Quantum mechanics and general relativity provide highly accurate descriptions of processes within their respective domains of applicability. However, unifying these theories into a single consistent system, as well as fully understanding the nature of fundamental constants, remain open problems.

Additional difficulties are associated with the interpretation of concepts such as mass, electric charge, and gravity, as well as with the existence of observed cosmological phenomena, including dark matter and dark energy, whose nature still lacks a generally accepted explanation.

A separate issue is the absence of a universal description of the structure of matter capable of consistently covering both microscopic and cosmological scales within a single principle.

This paper proposes an alternative theoretical approach based on the concept of the wave nature of matter and the fractal organization of physical processes.

The main hypothesis is that matter at all scales can be interpreted as a set of stable standing wave structures arising in a unified energy-saturated medium, considered as the physical vacuum.

Interactions between these structures are interpreted as manifestations of a universal resonance mechanism that determines both the dynamics of individual particles and their collective properties.

Within this approach, observed elementary particles can be considered as localized wave configurations, whose internal structure may be partially inaccessible to direct observation due to scale limitations and the nature of interactions.

A key distinction of the proposed approach is the interpretation of an elementary particle not as a point-like object, but as an extended standing wave structure.

In the standard quantum mechanical picture, the spatial properties of a particle are described through probability distributions, while the particle itself is considered a localized object. This paper adopts an alternative position: the wave configuration is interpreted as a physically real structure possessing a definite geometry and spatial scale.

In this approach, the observed probabilistic picture can be viewed as an effective description arising from the interaction and constraints of the measurement process, rather than as a fundamental property of the particle itself.

This allows linking the geometric characteristics of the wave structure with observable physical quantities, such as mass and electric charge, treating them as derived properties of stable wave regimes.

Within this interpretation, the transition to the standard quantum mechanical description is preserved and can be achieved by introducing an effective "point-likeness" associated with a region of informational opacity, while the extended wave structure determines the probability distribution of interaction.

The aim of this work is to develop a theoretical and mathematical model in which:

- the structure and properties of stable elementary particles (neutrino, electron, neutron, proton) are described through wave configurations;
- mass and electric charge are interpreted as characteristics of stable wave regimes;
- fundamental physical constants are interpreted through the properties of the wave medium;
- gravitational interaction is considered as a special case of a universal resonance mechanism;
- possible interpretations of quantum entanglement and cosmological effects (dark matter, dark energy) are discussed within the framework of fractal scaling.

The proposed approach does not negate existing physical theories, but rather regards them as limiting effective descriptions within a more general wave dynamics.

The goal is not to replace existing physics, but to attempt to provide a unified conceptual language capable of linking disparate levels of description of nature.

In contrast to the traditional approach, where physical quantities are introduced as independent entities with fixed dimensions, this work considers the possibility of their emergence as different levels of description of a single process.

In this context, dimensions act not as initial characteristics, but as a result of the chosen observational scale.

Additional clarification

The term "longitudinal component of the electromagnetic wave" is used hereafter. This does not imply the introduction of a new type of electromagnetic radiation. This term is used to denote the internal structure of the wave process associated with the energy distribution in the wavefront region and the finite spatial extent of the wave packet.

2. Postulates

The foundation of the proposed wave model of matter and the fractal structure of the Universe rests on the following postulates:

Postulate 1 — Primacy of energy

Energy is the fundamental physical entity that determines the existence and dynamics of all physical processes and objects. All observed phenomena are forms of its spatiotemporal organization.

Postulate 2 — Wave nature of matter

Matter consists of stable localized wave (standing) configurations in a continuous energy-saturated medium, which can be regarded as the physical vacuum.

Postulate 3 — Resonance as the universal mechanism of interactions

All physical interactions between stable wave structures are realized through the mechanism of resonant matching of their dynamic characteristics (frequency, phase, and spatial structure).

Postulate 4 — Fractal hierarchy of scales

The structure of matter and physical processes exhibits self-similarity under changes in the scale of description, where the transition between scales is accompanied by a change in the effective parameters of the system while preserving the overall structural dynamics.

Postulate 5 — Parametric nature of physical quantities

Observed physical quantities (mass, charge, characteristic size, and others) are parameters of the effective description of wave structures at a given scale level and are not absolute characteristics of objects. These parameters may transform during transitions between scale levels.

Postulate 6 — Observational limitation and information horizon

The observed structure of physical objects is determined by the limitations of information transfer and interaction between scale levels. When extreme conditions are reached, a region emerges in which the internal structure becomes inaccessible to external observation.

Postulate 7 — Unified nature of fundamental interactions

All fundamental interactions (gravitational, electromagnetic, weak, and strong) are different manifestations of a single resonance mechanism of interaction of wave structures, distinguished by their characteristic scales and matching regimes.

3. Conceptual foundations of the model

3.1. Wave representation of matter and the medium

Within the framework of the model, it is assumed that physical objects can be described as stable wave configurations arising in a continuous energy-saturated medium. Such a medium is considered as a carrier of wave dynamics, in which the localization of energy leads to the formation of stable structures interpreted as particles.

From the perspective of this approach, the properties of matter are determined not by point-like objects, but by the configuration of the wave field and its resonant regimes.

3.2. Fractality as a principle of scale self-similarity

Fractality in this model is understood as the property of preserving structural similarity of dynamic processes when transitioning between different scales of description.

It is important to distinguish between:

- the physical system as such;
- and its effective description at a given scale.

A change of scale leads to a change in observable parameters (characteristic sizes, frequencies, effective interaction speeds), but does not require the introduction of new fundamental laws.

3.3. Longitudinal component of the wave process

Within this work, an extended description of the electromagnetic wave process is introduced, in which a longitudinal component is considered as an element of the local wave structure.

By "longitudinal wave" in this model is meant not a separate type of fundamental field, but a component of the wave process associated with the spatiotemporal inhomogeneity of the wavefront and the finite spatial extent of the energy localization region.

In other words, it is not a new interaction that is being considered, but an alternative decomposition of the structure of an already known wave process, in which a component characterized by directionality along the local gradient of energy density is distinguished.

Such a representation is used as a model approximation that allows describing the processes of energy localization and the formation of stable wave nodes.

3.4. Resonance as a universal mechanism of interaction

Interactions between wave structures in the model are interpreted as the result of resonant matching of their characteristics.

Resonance is considered as the basic mechanism of energy transfer and redistribution in the system, determining the stability or decay of wave configurations.

Thus, fundamental interactions can be described through the conditions for matching the frequency and phase parameters of wave structures.

3.5. Informational limitation and observational horizons

The model introduces the concept of effective limited access to the internal structure of a system when observed from another scale.

This means that under certain conditions, the internal dynamics of the system become inaccessible to direct reconstruction at the external level of description, leading to the emergence of an effective "observation horizon."

Within this approach, such regions are considered as structures with extreme informational opacity arising from the dynamics of energy localization and scale limitations of interactions.

3.6. Functional analogy of structures at different scales

Based on the above principles, the existence of functionally similar structures at different scales of material organization is allowed.

It is emphasized that this is not about the identity of physical objects, but about the similarity of their dynamic properties within the corresponding level descriptions.

3.7. Black hole as a limiting regime of informational opacity

Within the framework of the model, a universal concept of a black hole is introduced as a limiting state of a wave system in which the possibility of reconstructing the internal structure from external observational data is lost.

Here, the term "black hole" is used not only in the astrophysical sense, but as a class of phenomena that share a common structural feature — the presence of a boundary beyond which information about the internal dynamics becomes inaccessible to the external level of description.

In physical interpretation, the *black hole* is a particular case of such a regime, realized in a gravitational field where an event horizon arises as a geometric boundary of causal connection.

Within the model, analogous limiting regimes can also arise at other scales if the dynamics of a wave configuration lead to an effective localization of energy that exceeds the possibility of external reconstruction of the system's internal structure.

3.8. Methodological note on dimensions

Within this work, a dimensionless representation of physical quantities is used. This may be perceived as a deviation from the traditional approach, in which dimensions are an integral part of physical equations.

However, in the proposed model, dimensions are considered not as fundamental properties of physical objects, but as derived characteristics that arise at the stage of forming a system of measurements.

This approach is discussed in detail in a separate work, "The Birth of Dimensions" (Zenodo: https://zenodo.org/records/19380194), where it is shown that numerical relationships can be considered primary, and dimensions — as a consequence of the choice of standards and observation scales.

In this sense, the dimensionless form of notation used in this work does not negate the physical content of the quantities, but corresponds to a more basic level of description that precedes the introduction of units of measurement.

If necessary, the transition to the standard dimensional form can be performed by introducing appropriate standards; however, to identify invariant relationships and fractal dependencies, it is more convenient to use a dimensionless representation.

4. Mathematical interpretation of the fractal structure and transitions between levels

4.1. Levels of description as a system of effective parameters

Within the framework of the model, a discrete hierarchy of scales for describing physical systems is introduced, denoted by a level index $n \in Z$. Each level corresponds to a distinct effective description of the same physical dynamics with its own set of parameters.

A key proposition is that physical quantities (mass, charge, characteristic size, and other observable parameters) in this model are not absolute characteristics of objects, but are considered as parameters of the level of description.

Within a fixed level n, these parameters are invariant and determine the observable physics at that scale.

4.2. Distinction between intra-level invariance and inter-level transformations

Within a single level of description, standard physical self-consistency holds: all measurable quantities remain stable and consistent with each other.

However, during the transition between levels $n \rightarrow n\pm1$, it is not the physical objects themselves that change, but rather the way they are effectively described.

Thus, two types of invariance are introduced:

- **Intra-level invariance** — the preservation of physical laws at a fixed scale;
- **Inter-level transformation** — the change of description parameters when the observation scale changes.

4.3. Fractal scale transition operator

The transition between levels is formalized through a scaling operator F acting on the set of system parameters:

$$F: \{Pn\} \rightarrow \{Pn + 1\}$$

where $\{P_n\}$ is the set of effective parameters of the system at level n.

The operator F reflects the change in description scale and determines how the system parameters transform during the transition between levels.

It is assumed that the structure of the operator possesses the property of self-similarity, i.e., it retains its functional form at all levels.

4.4. Loss of information and the formation of an observation horizon

During the transition between levels of description, a partial loss of information about the internal structure of the system occurs, due to the limited resolving power of the new scale.

This loss of information is not a physical destruction of the system, but rather an effect of description reduction, in which some internal degrees of freedom become unobservable.

Within the model, such boundaries are interpreted as a universal class of limiting regimes of informational inaccessibility, corresponding to the concept of a black hole as an observation horizon (*black hole*).

Thus, the observation horizon arises as a consequence of the transition between levels of description, not as a unique property of a specific astrophysical object.

4.5. Connection of the fractal transition with the resonance structure

The preservation of connectivity between levels is ensured by the resonant nature of interactions in the system.

It is assumed that stable configurations at different scales maintain structural correspondence through the matching of frequency and phase characteristics.

This makes it possible to interpret different levels as self-similar realizations of a single wave dynamics.

4.6. Physical meaning of scaling

Thus, scaling in the model should be understood not as a change in physical objects, but as a change in the level of their description. Physical quantities remain invariant within a level, but transform during transitions between levels according to the fractal operator F, which reflects the change in the degree of detail of the observed structure.

The observed structure of an object is determined not only by its internal state, but also by the scale of interaction through which the observation is made. Consequently, the limitation of information transfer is an invariant property of the fractal structure and arises as a result of the finite resolving power of the interaction between levels.

Depending on the observation scale, this limitation can be interpreted either as an internal boundary of the applicability of the description, or as a physical object analogous to a black hole, understood as a region of informational inaccessibility.

Thus, the distinction between "structure" and "collapse" is not absolute but scale-dependent, and is determined by the conditions of observation.

4.7. Interpretation of the "black hole" in terms of level transition

Within this model, a black hole can be interpreted as a limiting state that arises upon reaching the boundary of applicability of the current level of description, at which the maximum limitation of information transfer between scales occurs.

From this point of view, a black hole is not a separate physical entity, but represents a universal regime associated with the transition between levels of the fractal structure.

In such a regime, the observable system loses resolvability of its internal structure and can be described only through integral characteristics, which corresponds to the concept of a region of informational opacity.

5. Domains of interpretation of the model

The proposed model does not introduce new fundamental entities, but rather defines a unified principle for describing physical phenomena based on the scale-dependent nature of observation, the fractal structure of levels, and the limitation of information transfer.

Within this approach, a number of known physical effects can be considered as particular manifestations of the general principles underlying the model.

5.1. Interactions as manifestations of a single mechanism

Within the framework of the model, fundamental interactions can be regarded as different manifestations of a single mechanism of energy and momentum transfer in the medium.

The difference between gravitational, electromagnetic, strong, and weak interactions in this case is determined by:

- the scale of consideration,
- the nature of the stable structures,
- the conditions of resonant matching between them.

Thus, interactions are interpreted not as initially independent entities, but as regimes of the same process observed at different levels of description.

The constancy of the limiting speed of propagation of interactions (*c*) in this logic is associated with the conditions of coordinated exchange, under which stable information transfer within a given level is preserved.

Lorentz transformations, in turn, can be considered as a consequence of the change in the structure of interaction when transitioning to moving systems, rather than as an initial geometric property of spacetime.

5.2. Wave structure of particles and their properties

Particles in the model are considered as stable configurations of wave processes, whose characteristics are determined by their internal structure.

In this context:

- mass can be interpreted as a characteristic of the stability and amplitude of the localized process,
- electric charge — as a consequence of the geometric features of the configuration,
- spin and polarization — as manifestations of the internal symmetry and dynamics of the structure.

Wave-particle duality in this approach does not require a separate explanation but arises as a consequence of the fact that the observed "locality" is determined by the conditions of interaction, while the structure itself remains distributed.

The photon, in turn, can be considered as a limiting case of such a structure, in which there is no closed configuration providing localization at rest.

5.3. Quantum effects and system coherence

A number of quantum effects can be interpreted as manifestations of the coherence of processes within a unified medium.

Quantum entanglement in this case is considered as a state of a coherent structure for which the division into independent objects is an approximation arising at the observational level.

The limitation of information transfer plays a key role here: the observed "instantaneity" of correlations is not due to a violation of causality, but rather because the corresponding connection is not described in terms of spatial separation within a given level.

Similarly, effects such as fine spectral shifts can be regarded as a result of the interaction of local structures with changes in the medium manifesting at the corresponding scale.

5.4. Scale effects and cosmological manifestations

At large scales, the same principles lead to the interpretation of cosmological phenomena as consequences of the fractal structure.

Observed effects attributed to dark matter and dark energy can be considered as manifestations of:

- inhomogeneity of energy distribution,
- limitations of information transfer,
- and differences between levels of description.

In this context, the concept of a region of informational opacity plays a special role.

Such regions are characterized by the fact that within them, the standard description of interactions loses its applicability, and information transfer is limited. Depending on the observation scale, they can be interpreted either as boundaries of applicability of the model or as physical objects.

In particular, black holes can be considered as a special case of such a regime, in which the ultimate degree of information limitation is achieved.

From this point of view, the event horizon represents not only a geometric boundary but also a transition between different regimes of description, which is consistent with the previously introduced concept of scale dependence of observable structures.

5.5. Connection between quantum and classical descriptions

The model, by its nature, eliminates the rigid distinction between quantum and classical descriptions.

Discrete objects are interpreted as stable structures arising in a continuous medium, while their interactions obey laws that, in the limit of a large number of degrees of freedom, lead to classical behavior.

Thus, the difference between quantum and classical regimes is not fundamental but scale-dependent.

6. Potentially testable consequences of the model

The proposed model formulates a number of consequences that can be tested experimentally or through the analysis of observational data. These consequences are not direct predictions in the strict sense, but indicate directions in which the model can be confirmed or refined.

6.1. Scale correspondences and structural similarity

If the fractal principle is applicable to physical structures, one can expect the existence of scale-invariant relationships between objects at different levels.

This may manifest itself in:

- similarities in density distributions,
- the presence of characteristic scale coefficients,
- the recurrence of structural patterns.

Individual coincidences of parameters (for example, when comparing microscopic and astrophysical objects) may be considered as indications of a possible connection, but require systematic statistical verification to rule out random coincidences.

6.2. Role of environmental conditions in the characteristics of quantum systems

The model assumes that the properties of local structures may depend on the environmental conditions in which they exist, including energy density and interaction characteristics.

This may manifest itself in:

- variations of observable parameters under different conditions,
- the sensitivity of quantum systems to external fields and surroundings.

Experimental verification may involve high-precision measurements of the characteristics of particles and atomic systems under different gravitational and energetic conditions.

6.3. Limitation of information transfer and its observable effects

A key element of the model is the limitation of information transfer associated with the level of description.

This may manifest itself in:

- the existence of limits on measurement precision,
- features of quantum correlations,
- the boundaries of applicability of local descriptions.

In particular, quantum entanglement can be considered as one of the regimes in which the limitation of information transfer manifests itself in a nontrivial way.

6.4. Scale interpretation of compact astrophysical objects

Within the framework of the model, compact objects (including black holes) can be considered as regions in which the ultimate limitation of information transfer is achieved.

This leads to the following testable aspects:

- analysis of the properties of the event horizon as a boundary of description,
- investigation of radiation and dynamics near such regions,
- comparison of observed characteristics with models of transitions between levels.

6.5. Resonant properties of extended systems

If physical structures have a wave nature, then macroscopic objects can be expected to exhibit characteristic frequency regimes.

This is consistent with:

- observed oscillatory regimes (e.g., seismic),
- wave propagation in extended media.

Further research may be directed at identifying the relationship between the geometry of objects and their oscillation spectrum.

6.6. Possible variability of effective constants

Within the proposed model, the fine-structure constant α can be interpreted not as a fundamental unchanging constant, but as an effective coefficient characterizing the degree of manifestation of the electromagnetic interaction under given environmental conditions.

Since in the model the interaction of particles is considered as a result of the operation of the energetic medium, α may reflect not only the internal properties of the wave structures themselves, but also the parameters of the surrounding space. In particular, the gravitational field, by changing the local characteristics of the medium (such as energy density and spacetime geometry), can potentially affect the observed effectiveness of the electromagnetic interaction.

In this sense, α can be regarded as a parameter dependent on background conditions, rather than a strictly universal constant. At the same time, under ordinary conditions (near the Earth's surface), the possible variability of α remains below the threshold of experimental sensitivity, creating the illusion of its absolute constancy.

Thus, the model allows for the existence of small but fundamentally measurable deviations of α under different gravitational or energetic conditions, which opens up the possibility of experimental verification.

7. Mathematical model of the structure of elementary particles in space

Introduction

In this chapter, an attempt is made to construct a simplified mathematical framework in which elementary particles are considered as stable standing wave configurations with a discrete number of nodes. This approach allows linking the observable characteristics of particles with the geometry of their wave structure and with scaling processes during transitions between fractal levels.

The goal is not to construct a complete quantitative theory of elementary particles. The main aim is to show that even the simplest geometric relationships applied to wave structures can yield values of physical parameters comparable to observed ones. The results obtained should be regarded as an indication of a possible deep connection between the geometry of wave processes and the fundamental characteristics of matter.

In physics, what is observed is not abstract objects in themselves, but their interaction with space, manifested through the distribution of energy and momentum. In this sense, any elementary particle within this model is interpreted as a localized wave structure — a stable energy distribution possessing a definite geometry. Accordingly, characteristics such as mass and charge are considered as integral properties of this structure: mass as a measure of energy localization, charge as a characteristic of the interaction of the wave configuration with an external field.

To substantiate the representation of an elementary particle as a wave structure, this work uses Appendices 1, 2, and 3. The principle of scalability (fractality) under conditions of a finite speed of propagation of interactions is discussed in Appendix 6.

Within this chapter, attention is limited to four observable stable particles — the neutrino, electron, proton, and neutron (as well as their antiparticles). It is assumed that these particles may correspond to the simplest stable wave configurations. This assumption is model-based and does not exclude the existence of more complex or less stable states.

Although the free neutron is unstable, in this model it is considered as a quasi-stationary wave structure that maintains its integrity over a finite interval of time. Its instability may be related to features of its internal dynamics, including the possible presence of a rotational component of energy distribution.

As a basic assumption, it is taken that a decrease in the characteristic wavelength corresponds to an increase in energy and, consequently, in the effective mass of the structure. This is consistent with the general properties of standing waves, where an increase in the number of nodes leads to an increase in energy and a decrease in the characteristic scale.

The observational fact that only some particles (e.g., the electron and proton) possess an electric charge is interpreted as a possible consequence of differences in the structure of wave configurations, in particular their symmetry properties. Within the model, it is assumed that this may correspond to the parity of the number of nodes, although this claim requires further refinement.

Special attention is given to the comparison of particle masses. In particular, the difference between the neutron mass and the proton mass is interpreted not as a direct contradiction of the model, but as an indication of a possible influence of internal dynamic processes on the observed value of mass. This difference may be associated with additional forms of energy motion within the structure, which manifest in experiment as a contribution to the effective mass.

The principle of formation of wave structures of particles is discussed in Appendix 3. Broader conceptual issues, including the origin of interactions, are addressed in a separate work, "Reflections: Faith, Unbelief. Spirit and Matter" (https://zenodo.org/records/19260065).

It should be noted that this work uses a non-traditional approach to the question of dimensions: in a number of relationships, dimensionless combinations based on characteristic frequency parameters are considered. This is related to the assumption of the primacy of wave processes and frequency relations over introduced systems of units. At the same time, numerical estimates are compared with quantities expressed in the SI system.

This approach is preliminary and requires further development. Possible grounds for such consideration are discussed in the work "The Birth of Dimensions" (https://zenodo.org/records/19380194), which attempts to relate physical quantities to more fundamental frequency relationships.

7.1 Relationship between dimensions and weight

7.1.1 Initial data:

To describe an elementary particle as a wave structure, consider an electromagnetic disturbance that has finite spatial extent and internal structure. Within the model, such a structure is interpreted as a stable configuration of a wave process.

The description employs a decomposition of the wave process into two interrelated components, which can be conditionally interpreted as:

- **longitudinal** — characterizing the spatial distribution and extent of the structure,
- **transverse** — associated with the amplitude characteristics and energy distribution.

Here, the term "longitudinal component" is used in an extended sense and does not introduce a new type of wave; rather, it reflects the consideration of the same electromagnetic structure from the viewpoint of its spatial localization and finite "thickness" of the front.

As a basic assumption, it is accepted that the characteristic speed of propagation of interactions in such a structure is limited by the speed of light cc, which corresponds to the fundamental limit on the transmission of disturbances in space.

For a simplified description, a representation is introduced in which the wave process can be considered as having two interrelated components responsible for:

- the spatial scale of the structure,
- the energy characteristic (associated with the energy density).

It is assumed that these components are not independent but are linked through the common limitation on the speed of propagation of disturbances. In a simplified model, this can be expressed by the relation:

$$\upsilon_x^2 + \upsilon_y^2 = c^2.$$

where υ_x and υ_y are effective components characterizing the distribution of the wave process between the spatial and energy components.

This relation should not be understood as a decomposition of the particle's velocity in space, but rather as a model representation of the balance between the geometry of the structure and its energy content.

The quadratic form of this relation is chosen because we are dealing with independent contributions to the common limitation associated with the propagation of disturbances. In such situations, a Euclidean metric naturally arises, where summation is performed over the squares of the components.

A similar approach is used, for example, when considering independent components of velocity or energy, where the contribution of each component is determined by its square. Within this model, this relation should be considered not as a strict physical equality, but as a minimal geometric approximation reflecting the balance between different aspects of the wave process.

It is interesting to note that the appearance of quadratic relations in this context is consistent with a more general view of the nonlinearity of wave processes. In particular, the work "The Birth of Dimensions" (https://zenodo.org/records/19380194) introduces the idea of forming new levels of description as a result of the superposition of wave structures ("wave upon wave"), which naturally leads to quadratic and higher power-law dependencies.

In this sense, the relation used here can be regarded as a special case of a more general principle, according to which observable quantities arise as a result of the nonlinear interaction of basic processes.

Thus, within the framework of this approach, the geometric parameters of the wave configuration turn out to be directly related to the energy distribution, which provides a basis for establishing a relationship between size and mass.

The connection to mass is introduced through the well-known relation between energy and mass, which allows the energy component of the wave structure to be interpreted as an effective mass.

(Note: In this section, for simplicity of mathematical expressions, emphasis is placed on numerical relationships, and physical dimensions are omitted in some cases. The values used are consistent with the SI system. Restoring dimensions requires separate consideration.)

7.1.2 Derivation of Limiting Sizes and Masses for Standing Waves

For a stable standing wave structure to exist, different regions of this structure must be able to remain in an interconnected state. Within the framework of the model under consideration, this means that the characteristic time for the propagation of interaction inside the structure must be comparable to its size.

In other words, the maximum size of a wave configuration is limited by the condition that the disturbance manages to "coordinate" its various parts over a finite time.

If we denote the characteristic interaction time as Δt, then the limiting size of the structure can be estimated as:

$$L \sim c\Delta t$$

In the simplest case, when the interaction is considered as a process with a single characteristic component, a natural limitation is the condition:

$$\Delta t \sim \frac{1}{c}$$

However, within this model, the wave process is considered as having two interrelated components (spatial and energetic), which leads to a stricter constraint on the characteristic interaction time. The minimal estimate is taken as:

$$\Delta t \sim \frac{1}{c^2}$$

Such an assumption should be considered as a model one, reflecting the need to simultaneously coordinate different aspects of the wave structure.

Then the maximum characteristic size of a standing wave is estimated as:

$$L_{max} \sim c \cdot \frac{1}{c^2} = \frac{1}{c}$$

1. Limiting Sizes (L)

Thus, the maximum size of a stable wave structure is determined as:

$$L_{max} \sim \frac{1}{c}$$

The minimum size can be estimated by applying a similar reasoning to the internal structure of the wave. If we consider the nesting of wave configurations, the characteristic scale decreases proportionally to the same factor:

$$\mathrm{L_{min}} \sim \frac{1}{c^2}$$

Consequently, the range of possible sizes of stable standing waves can be estimated as:

$$\frac{1}{c^2} \leq \mathrm{L} \leq \frac{1}{c}$$

This result should be considered as an estimate that sets the order of magnitude.

2. Limiting Masses (M)

Within the model, mass is associated with the energy of the wave structure. Energy, in turn, is determined by the amplitude distribution of the wave, which in this case has a spatial geometry close to spherical.

As a characteristic factor accounting for geometry, a coefficient 2π is introduced, reflecting the circular structure of the wave process.

Then the energy range can be estimated as:

$$\mathrm{E} \sim \frac{2\pi}{c^2} \text{ to } \frac{2\pi}{c}$$

Using the relation between energy and mass:

$$\mathrm{E} = \mathrm{Mc}^2$$

we obtain the range for mass:

$$\frac{2\pi}{c^4} \leq \mathrm{M} \leq \frac{2\pi}{c^3}$$

Thus, both size and mass turn out to be power-law related to the speed of light.

It is important to note that the ratio of the limiting values in each range is determined by the same quantity:

$$\frac{\mathrm{L_{max}}}{\mathrm{L_{min}}} \sim \mathrm{c}, \frac{\mathrm{M_{max}}}{\mathrm{M_{min}}} \sim \mathrm{c}$$

This indicates the possibility of a power-law nature of quantization of states within the framework of the model.

3. Connection with Fundamental Constants

It is interesting to note that the expression:

$$\frac{2\pi}{c^4}$$

is numerically close to the value of Planck's constant:

$$\mathrm{h} \approx 6.63 \times 10^{-34}$$

whereas:

$$\frac{2\pi}{c^4} \approx 7.76 \times 10^{-34}$$

Similarly:

$$\frac{1}{c^4} \sim \hbar$$

Such a coincidence may be considered as an indication of a possible connection between fundamental constants and the geometry of wave processes.

At the same time, the obtained values should not be interpreted as an exact derivation of Planck's constant. Rather, it is a matter of the simplest relations based on the limitation of the propagation speed of interactions leading to quantities of the same order.

Possible discrepancies may be related to the fact that real physical systems take into account more complex effects, including the distribution of energy in space and the interaction of different parts of the wave structure.

This issue requires separate consideration and is beyond the scope of the current section.

7.1.3 Quantization of Nodes and Parameters of Elementary Particles

1. Condition for Node Formation

For the formation of stable standing wave nodes, it is necessary to coordinate various components of the wave process. Within the previously introduced model, this can be interpreted as a balance between the components responsible for the spatial distribution and the energy characteristic of the structure.

In a simplified representation, the stability condition can be associated with a uniform contribution of these components. This corresponds to a situation where their effective "projections" are comparable:

$$v_x \sim v_y$$

In polar representation, this condition leads to the relation:

$$\cos\theta \sim \sin\theta$$

which is realized for angles of the form:

$$\theta = \frac{\pi}{4} + \frac{n\pi}{2}, \mathrm{n} \in \mathrm{Z}$$

Thus, a finite number of symmetric directions are distinguished on the circle, for which the component balancing condition is satisfied.

This suggests that stable nodal structures are formed only for a limited number of configurations corresponding to the simplest symmetric cases.

Within the model, four basic configurations arise naturally, which can be associated with wave structures having a small number of nodes.

This statement should be considered as a model assumption reflecting the system's tendency toward the simplest stable symmetric states.

Physically, this means that a stable node arises when the wave structure ensures a uniform distribution of energy among different directions. When one of the components strongly dominates, the system either transitions into a propagation regime (without forming a standing structure) or becomes unstable.

2. Principle of Power-Law Quantization

It was previously shown that the characteristic ranges of sizes and masses are determined by power-law dependencies on the speed of light. This suggests that discrete states within these ranges may also be formed according to a power law.

As a model assumption, a finite number of characteristic levels corresponding to the most stable configurations of the wave structure is introduced. To describe the transition between them, it is convenient to introduce an additional "scale step," which can be interpreted either as the applicability boundary of the current description level or as a transition to the next fractal level.

In the simplest version, this leads to the introduction of an effective number of divisions of the range equal to five, where four correspond to stable configurations and the fifth to a transitional state.

With this approach, the scaling of parameters can be described by a power-law factor of the form:

$$\mathrm{k} = \left(\frac{c}{2\pi}\right)^{1/5}$$

This expression should be considered as a model parameter defining the characteristic step between levels.

3. Determination of Particle Parameters

Using the introduced scale factor, expressions for the parameters of wave structures depending on the number of nodes n can be written.

It is assumed that with an increase in the number of nodes:

- the characteristic size decreases,
- the energy characteristic (and, accordingly, the effective mass) increases.

Then, for the amplitude of the longitudinal component (associated with mass), one can write:

$$M_0 \sim \frac{2\pi}{c^4}\left(\frac{c}{2\pi}\right)^{\frac{n}{5}}, 1 \le n \le 4$$

Similarly, for the characteristic wavelength:

$$\lambda_0 \sim \frac{1}{c}\left(\frac{c}{2\pi}\right)^{-\frac{n}{5}}, 1 \le n \le 4$$

The estimated diameter of the wave structure can be evaluated as:

$$d_0 \sim \frac{n+1}{2}\lambda_0$$

Thus, the parameters of wave configurations turn out to be related to the number of nodes through a simple power law determined by the fundamental constant c.

The obtained expressions should be considered as estimates reflecting the general nature of the dependence, rather than as exact formulas.

Remark

In this section, mass is understood as the amplitude characteristic of the longitudinal component of the wave structure. The total mass of a particle as a complex system comprising several regions with different energy densities will be discussed in subsequent sections.

Interpretation of the Obtained Size and Physical Properties

The obtained value d_0, which characterizes the size of the standing wave structure, is interpreted within this model as the full spatial scale of an elementary particle.

In contrast to the standard quantum mechanical interpretation, where a particle is considered a point-like object and its spatial characteristics are described through a probability distribution, this work adopts a different position: the particle is identified with the wave configuration itself.

Thus, a standing wave is regarded not as an auxiliary mathematical construct, but as a physically real structure possessing a definite geometry and extent.

The observed "fuzziness" of a particle's position in experiments can then be associated not with the fundamental probabilistic nature of the object, but with the features of interaction and the limitations of the measurement process.

The transition to the quantum mechanical interpretation within this model can be carried out as follows: the region of informational opacity is taken as an effective "point-likeness", while the extended standing wave structure is interpreted as a probability distribution of interaction.

In this approach, the probabilistic description is not a fundamental property of the particle, but arises as a consequence of observational limitations and the features of interaction with its full wave structure.

It should also be noted that in the standard interpretation, fundamental characteristics such as mass and electric charge are introduced as independent parameters not directly related to the spatial structure of the object.

The proposed model adopts a different position: since the particle is identified with the wave configuration, its physical properties can be interpreted as consequences of the geometry and dynamics of this structure.

Thus, mass and electric charge are regarded not as primary, given quantities, but as derived characteristics that arise as a result of the formation of a stable standing wave in the energy medium.

7.2 Extreme States of Wave Structures: From Photons to Limits of Energy Compression

In addition to the previously considered stable standing configurations associated with elementary particles (with values n=1,2,3,4), the model also introduces limiting states characterized by the values n=0, n=−1, and n=5.

These states do not correspond to stable massive particles but can be interpreted as other regimes of existence of wave processes — in particular, as propagating electromagnetic disturbances (photons and classical waves) and limiting states of energy localization associated with transitions between fractal levels.

Thus, the considered set of $\boldsymbol{n}$ values makes it possible to cover both stable localized structures and boundary regimes corresponding to the transition between different forms of energy manifestation.

7.2.1. States n=0 and n=−1: Photons and Electromagnetic Waves

States with n=0 and n=−1 within this model characterise electromagnetic radiation, particularly photons, and their transition to classical electromagnetic waves.

7.2.1.1 Limiting Wavelengths of the Photon

Using the previously obtained expression for the characteristic wavelength:

$$\lambda_0 \sim \frac{1}{c}\left(\frac{c}{2\pi}\right)^{-\frac{n}{5}},$$

we can consider the limiting states of wave configurations corresponding to the values n=0 and n=−1.

These states do not correspond to stable standing waves (particles with mass) but can be interpreted as boundary regimes associated with the propagation of electromagnetic radiation.

State n=0 (minimum characteristic wavelength of the photon)

In this case, we obtain:

$$\lambda_{\min} \sim \frac{1}{c}$$

Numerically:

$$\lambda_{\min} \approx 3.3 \cdot 10^{-9} m$$

This state can be interpreted as the limit at which the wave structure does not yet form the closed standing configuration characteristic of massive particles, but already possesses pronounced localization. In this regime, the wave process is characterized by a high degree of spatial energy concentration and can be considered as the limiting case of a directed quantum of radiation.

State n=−1n=−1 (maximum characteristic wavelength of the photon)

For this case:

$$\lambda_{\max} \sim \frac{1}{c}\left(\frac{2\pi}{c}\right)^{\frac{1}{5}}$$

Introduce the notation:

$$K_s = \left(\frac{2\pi}{c}\right)^{\frac{1}{5}}$$

Then:

$$\lambda_{\max} \sim \frac{1}{c} K_s$$

Numerically:

$$\lambda_{\max} \approx 1.1 \cdot 10^{-7} m$$

This state can be interpreted as the limit at which the wave structure loses the features of a localized quantum and transitions to more extended forms of propagation. In this regime, the energy is distributed more uniformly in space, and the behavior of the system approaches the classical description of electromagnetic waves.

Thus, within the framework of the model, the photon can be considered as a wave configuration existing in the range:

$$\frac{1}{c} \leq \lambda \leq \frac{1}{c}\left(\frac{2\pi}{c}\right)^{\frac{1}{5}}$$

where the lower bound corresponds to the maximally localized state, and the upper bound corresponds to the transition to extended wave regimes.

The obtained estimates should be regarded as indicating characteristic scales, rather than as rigid physical boundaries of the electromagnetic spectrum.

7.2.1.2 Mechanism of Photon Birth

In standard physics, a photon arises during transitions between energy states of a system, for example, when an electron transitions between levels in an atom. Such a transition is accompanied by a change in energy distribution and, as a rule, by the accelerated motion of charged particles.

Within the framework of the proposed model, this process can be interpreted as a rapid localized redistribution of energy density in space.

It is assumed that this redistribution has a directional character and can be represented as the formation of a disturbance that has both spatial and energetic components.

In terms of the previously introduced decomposition, this corresponds to the simultaneous emergence of:

- a longitudinal component associated with the redistribution of energy density in the direction of propagation,
- a transverse component manifesting as an electromagnetic field.

Here, these components are not independent processes but represent different aspects of a single wave disturbance.

Since the process of photon formation occurs over a finite time and in a limited region of space, the emerging wave structure does not have time to transition into a fully symmetric (closed) configuration characteristic of standing waves.

As a result, an asymmetric, propagating wave configuration is formed, in which energy is directed predominantly along the direction of emission.

Within the model, such a structure can be interpreted as an "open" wave shell, differing from closed standing configurations.

Geometrically, this can be associated with an elongated forward shape reflecting the directionality of energy transfer. However, this representation should be considered as an illustrative interpretation rather than an exact description of the photon's shape.

Thus, in this model, the photon arises as a transient regime of the wave process, in which energy leaves the localized structure and transitions into a propagating state.

7.2.1.3 Properties of the Photon

Within the framework of the model under consideration, the properties of the photon can be interpreted as a consequence of its wave nature and the features of its formation as a propagating, unclosed configuration.

Zero Rest Mass

The absence of a closed standing structure capable of holding energy in a localized state leads to the photon having no rest mass. In this interpretation, rest mass is associated with the possibility of the existence of a stable localized configuration. Since the photon is a propagating disturbance, such localization is absent, which is consistent with the observed property of zero rest mass.

Energy, Momentum, and Directionality

Despite the absence of rest mass, the photon carries energy and momentum, which corresponds to the well-known relation $E=pc$. Within the model, this can be related to the fact that the wave structure of the photon is asymmetric and propagating, with a predominant transfer of energy in one direction.

The previously introduced concept of longitudinal and transverse components should be interpreted as a description of the energy distribution during propagation, rather than as the presence of independent components. In this sense, the directionality of the photon arises as a result of the coordinated motion of the entire wave configuration.

The equivalence of mass E/c^2 in this model reflects not the presence of rest mass, but the energy content of the propagating disturbance.

Spin

The spin of the photon in standard physics is associated with its polarization and the internal symmetry of the electromagnetic field. Within the proposed model, it can be assumed that spin reflects features of the internal structure of the propagating wave, in particular, the nature of its symmetry with respect to the direction of motion.

This can be interpreted as the presence of a certain "twist" or rotational component of the wave process. However, this representation is qualitative in nature and requires a more rigorous mathematical description.

Thus, the basic properties of the photon can be considered as a consequence of the fact that it is not a closed standing structure, but a propagating wave disturbance located at the boundary between localized and extended regimes of energy existence.

7.2.1.4 Transition to Classical Electromagnetic Waves

As the radiation frequency decreases (i.e., as the characteristic wavelength increases and transitions to values $n \to -1$ and below), the process of changing the energy state of the source becomes slower and more spatially extended.

Within the framework of the model, this means that the emerging wave disturbance loses the pronounced localization characteristic of the photon as a quantum of radiation.

In this regime, the spatial distribution of energy becomes more uniform, and the wave structure approaches a continuous propagation process described by classical electrodynamics.

Geometrically, this can be interpreted as a transition from a localized "convex" wave configuration to a more extended and smoothed form, where characteristic inhomogeneities become small compared to the wavelength.

In this case, the directionality of the radiation is no longer determined by the internal structure of an individual wave disturbance, but by the boundary conditions of the source (e.g., the geometry of the antenna) and the conditions of propagation in the medium.

Thus, in this model, the classical electromagnetic wave can be considered as a limiting case that arises during the transition from discrete, localized wave states to a continuous regime of energy distribution in space.

7.2.2 State n = 5: Energy Compression Limit and Fractal Transition

The state corresponding to n=5n=5 represents, within the framework of the model, the opposite limiting case relative to propagating wave regimes (such as the photon).

Characteristics of the State

The previously introduced relation between the components of the wave process allows for a situation in which the contribution associated with the energy component becomes dominant. In the limiting case, this can be interpreted as a state in which the wave structure loses spatial extent and is characterized by maximum energy concentration.

This state should be considered as a model limit rather than an observable configuration.

Size and Nature of the State

Using the previously introduced estimates, it can be assumed that the characteristic scale of such a configuration turns out to be smaller than the minimum size characteristic of stable standing waves (with n=1…4):

$$L < \frac{1}{c^2}$$

This indicates a transition to a regime in which the standard description of the wave structure within the current level ceases to be applicable. In this sense, this state can be interpreted as a region of extreme energy concentration — analogous to the previously introduced region of informational opacity.

Connection with "Pointlikeness" and Quantum Description

Within the framework of the model, such regions can be considered as limiting centers of energy localization, which at a higher level of description manifest as "point-like" objects. This provides a way to qualitatively relate the concept of a point particle to the limitations of the wave description. In this approach, the use of wave functions in quantum mechanics can be regarded as an effective way to describe the behavior of a system near such regions.

Connection with Gravitational Effects

Since the state under consideration is associated with a high concentration of energy, one can expect that at corresponding scales, effects analogous to gravitational ones begin to play a role. Within the model, this allows the interpretation of such states as sources of disturbances propagating in all directions and manifesting as collective oscillations of the medium.

At the macroscopic level, such processes can be associated with phenomena described as gravitational waves or internal oscillations of massive systems. However, this interpretation is qualitative in nature and requires further refinement.

Thus, the state n=5 can be considered as a limiting regime of the wave model, corresponding to a transition beyond the applicability boundary of the current level of description.

Together with the states n=0 and n=−1, this allows the description of the full spectrum of regimes — from maximally localized to fully propagating, including transition regions associated with the fractal structure of space.

7.2.3 High-Energy Quanta from Nuclear Interactions (Gamma Radiation)

A special type of high-energy electromagnetic radiation — gamma quanta — can be interpreted within this model not only as a result of annihilation or transitions between energy levels, but also as a consequence of deeper processes associated with the restructuring of the wave structures of nucleons (protons and neutrons).

If a nucleon is considered as a complex standing wave configuration consisting of several interconnected regions of increased energy density, then during intense interactions (e.g., in nuclear reactions), a redistribution of this structure may occur, accompanied by the release of localized energy disturbances.

Such disturbances can be interpreted as separate fragments of the wave process possessing the following characteristics:

- They carry significant energy associated with the local energy density inside the original structure.
- Their characteristic spatial scales are comparable to the sizes of nucleons (on the order of $10^{-15} \ldots 10^{-16}$ m), which corresponds to the high-energy range of radiation.
- Being formed during a rapid redistribution of energy, such wave configurations do not have time to transition into a symmetric or closed state. As a result, a propagating disturbance arises with a pronounced directionality of energy transfer.

- Despite possible localization, such structures do not satisfy the conditions for stable standing waves (considered for n=1…4n=1…4) and therefore cannot exist as particles with rest mass. Their energy is realized in the form of a propagating quantum of radiation.

Thus, gamma radiation in this model can be considered as a result of the transition from complex localized wave structures to propagating regimes during their restructuring at the nucleon level.

Unlike radiation arising from electronic transitions, gamma quanta are associated with deeper levels of matter organization, which is reflected in their higher energy and smaller characteristic scales.

At the same time, their corpuscular properties can be interpreted as a consequence of the high degree of energy localization at the moment of formation, whereas their wave nature manifests itself in the process of further propagation.

The detailed internal structure of such excitations is not fixed within the framework of this work, since it depends on the specific conditions of formation and requires a more precise description.

7.3 Features of Elementary Particles in the Wave Model

Within the framework of the proposed model, stable elementary particles can be associated with the simplest standing wave configurations characterized by a small number of nodes.

Four basic configurations are considered as a model correspondence, which can be related to the observed stable particles — the neutrino, electron, neutron, and proton.

In this mapping, the numbers of nodes n=1,2,3,4 are assigned to the aforementioned particles, with an increase in ***n*** associated with the increasing geometric complexity of the wave structure and changes in its energy characteristics.

Such a representation makes it possible to interpret the properties of particles as a consequence of the geometry and dynamics of the corresponding wave configurations, without introducing them as independent primary parameters.

It should be emphasized that this correspondence is of a model nature and reflects the aim of identifying the simplest stable regimes of the wave process that can be compared with observed particles.

7.3.1 Neutrino (n = 1)

Structure and size: For n=1, the simplest standing wave configuration with a minimal number of nodes is formed. According to the relations obtained in Section 7.1.3, this state is characterized by the largest wavelength λ_0 and, accordingly, the largest size of the wave structure among the particles under consideration. Within this model, this size is interpreted as the full spatial scale of the particle.

Mass: The neutrino corresponds to the minimum value of the wave configuration amplitude M_0, which manifests as an extremely small mass.

Interaction: Despite the significant spatial scale of the wave structure, the neutrino hardly interacts with matter. Within the model, this may be related to the extremely low energy density distributed throughout its wave configuration. In other words, given its large characteristic size and small mass, the energy density of such a structure turns out to be significantly lower than that of most observed particles. Interaction with denser objects then becomes extremely inefficient, since there is insufficient energy localization necessary for a meaningful exchange. Thus, the neutrino can be regarded as an extended but energetically "rarefied" wave structure, which leads to its weak interaction with matter.

Internal dynamics: The configuration with n=1 is characterized by the absence of a stable symmetric structure, which leads to a dynamic redistribution of energy inside the wave system. This may manifest as an internal circulation or rotation of energy density.

Charge: The absence of electric charge is interpreted as a consequence of an odd number of nodes and the lack of a stable boundary configuration necessary for the formation of a directed electromagnetic interaction.

Quantum entanglement (a possible interpretation): Within the framework of the model, states with an odd number of nodes are characterized by internal dynamic imbalance, which can lead to the formation of correlated states upon their creation. In this sense, the neutrino, as a configuration with n=1, may also possess properties analogous to quantum entanglement. However, due to its extremely weak interaction with matter, the experimental registration of such effects appears to be substantially more difficult.

7.3.2 Electron (n = 2)

Structure and charge: For n=2, a standing wave configuration with an even number of nodes is formed. Within the model, such configurations are characterized by a more symmetric energy distribution compared to the n=1 state. It is assumed that this symmetry leads to the formation of a stable boundary structure capable of providing directed electromagnetic interaction, which is interpreted as the presence of electric charge.

Nature of charge: In this model, electric charge is associated with the work performed by the energy medium during the formation of the boundary half-wave of the standing structure. Since this work turns out to be invariant for elementary wave configurations, this provides a natural explanation for the quantization and universality of the elementary charge.

Mass and size: Compared to the n=1 state, the configuration with n=2 is characterized by a smaller wavelength λ_0 and a smaller characteristic size d_0, along with an increase in amplitude M_0. This corresponds to an increase in the energy density of the wave structure and manifests as an increase in mass and a strengthening of interaction with surrounding matter.

7.3.3 Neutron (n = 3)

Structure and internal dynamics: For n=3, a standing wave configuration with an odd number of nodes is formed. Within the model, such states are characterized by a violation of the symmetry of energy distribution necessary for the formation of a stable boundary structure. This may lead to the emergence of internal dynamics — circulation or redistribution of energy inside the wave system, similar to the n=1 state, but with a significantly higher energy density.

Charge: The absence of electric charge is interpreted as a consequence of an odd number of nodes and the lack of a stable boundary configuration that would provide directed electromagnetic interaction.

Mass and size: Compared to the electron, the configuration with n=3 is characterized by a smaller wavelength λ_0 and a smaller size d_0, along with an increase in amplitude M_0, which corresponds to an increase in energy density.

A peculiarity arises here: the experimentally observed mass of the neutron is slightly greater than the mass of the proton, despite the fact that within the basic wave model (taking into account only the standing wave amplitude) the opposite relationship is expected.

Within the proposed interpretation, this discrepancy may be related to the additional internal dynamics of the system. The energy associated with internal redistribution or circulation of energy density may manifest in interactions as a contribution to the effective (observed) mass.

Thus, the observed mass of the neutron may reflect not only the "geometric" component related to the amplitude of the wave structure, but also a dynamic contribution arising from its internal state.

Quantum entanglement: For states with an odd number of nodes, the presence of internal dynamic imbalance is assumed, which may lead to the formation of correlated states upon their creation. In particular, during the formation of neutron–antineutron pairs, such systems may be in a coordinated state, which manifests as quantum entanglement and can influence their further evolution and decay.

7.3.4 Proton (n = 4)

Structure and charge: For n=4, a standing wave configuration with an even number of nodes is formed. Similarly to the n=2 state, such configurations are characterized by a more symmetric energy distribution and the presence of a stable boundary structure that provides directed electromagnetic interaction. This is interpreted as the presence of electric charge.

Sign of charge: Within the model, it is assumed that the sign of the charge is determined by the direction or phase orientation of the boundary half-wave formation process. For the n=2 and n=4 states, these configurations turn out to be opposite, which may lead to a difference in the sign of the electric charge of the electron and the proton.

Mass and size: The configuration with n=4 is characterized by the smallest wavelength λ_0 and the smallest size d_0 among the considered states, with the maximum value of amplitude M_0. This corresponds to the highest energy density and manifests as the maximum mass and high stability of the particle.

Stability: Unlike states with an odd number of nodes, the n=4 configuration possesses a more stable symmetry and the absence of pronounced internal dynamic imbalance. This may be associated with the high stability of the proton and its resistance to decay under ordinary conditions.

7.3.5 General Principle: Internal Dynamics and Charge

The conducted analysis allows us to identify a general pattern: for stable wave configurations with a small number of nodes, there is a difference in the nature of their interaction with the surrounding environment.

In particular, states with an odd number of nodes (n=1,3) are characterized by the presence of internal dynamics — circulation or redistribution of energy inside the wave structure.

For states with an even number of nodes (n=2,4), a more symmetric configuration with a stable boundary structure is formed, which leads to the appearance of electric charge and directed electromagnetic interaction.

Thus, within the framework of the model, one can speak of two different ways in which the wave structure manifests itself: through internal dynamics or through the formation of boundary interaction. These mechanisms reflect different regimes of interaction of the particle with the energy medium.

7.3.6 Pair Production of Particles

In accordance with the law of energy conservation, the formation of wave structures from the energy medium must occur while preserving the total characteristics of the system. This leads to the fact that particle production is considered a pair process (particle–antiparticle).

Within this model, the difference between such pairs can be associated with the opposite orientation of the internal dynamics of the wave structure or with the opposite direction of formation of the boundary configuration, which manifests as a difference in the sign of charge.

For neutral particles (e.g., neutrino–antineutrino or neutron–antineutron), this difference may be expressed in opposite directions of internal energy circulation.

Such correlated states at birth can lead to the formation of coordinated systems, which is interpreted as a manifestation of quantum entanglement.

Thus, the properties of elementary particles within the model naturally follow from their representation as standing wave configurations with different numbers of nodes.

This allows us to consider the set of observed particles as a manifestation of a limited number of stable wave regimes.

7.3.7 The Nature of Quarks and the Origin of Fractional Charges in the Wave Model

7.3.7.1 The Quark as an Element of the Wave Structure

As established earlier, stable elementary particles within the framework of the model represent standing waves with a number of nodes n, consisting of $n+1$ half-waves. Each half-wave corresponds to a localized region of energy density variation, formed by the invariant work of space.

The stability of the particle is ensured by the integrity of the entire wave configuration and the consistency of its internal resonance. Individual half-waves cannot exist as independent objects, since their isolation would lead to the destruction of the entire structure.

In experiments with high energy transfer (e.g., in deep inelastic scattering processes), it is observed that the particle behaves as if it consists of localized interaction centers. In the Standard Model, these objects are interpreted as quarks.

Within the proposed model, such observations can be interpreted differently: quarks are not fundamental point-like particles, but rather manifestations of the internal structure of the standing wave — localized segments or combinations of half-waves that manifest as separate objects during interaction.

Thus, a quark can be considered as a quasiparticle corresponding to a localized region of the hadron's wave structure, possessing effective interaction characteristics.

The introduction of the concept of an effective charge for such segments is related to the distribution of the total work of the wave structure. Although the total charge of the particle is determined by its full configuration, an interaction density distribution may arise inside it, manifesting as fractional effective values.

This approach naturally allows one to interpret the phenomenon of confinement: an attempt to isolate an individual segment of the structure leads to the destruction of the resonant state and requires energy sufficient to form a new stable wave configuration (e.g., a hadron pair).

7.3.7.2 Mechanism of Deep Inelastic Scattering and the Role of Helicity

To understand the processes associated with probing the internal structure of hadrons, as well as the differences in the interaction of neutrinos and antineutrinos with various components of hadrons, we consider the mechanism of deep inelastic scattering within the framework of the wave model.

Relativistic localization of the probe: Probe particles (electrons, muons, neutrinos) used in experiments are accelerated to relativistic speeds. At the same time, their effective de Broglie wavelength decreases to scales comparable to the characteristic sizes of hadrons ($\sim 10^{-15}$ m) and smaller. Within the wave model, this means that the effective interaction region contracts, allowing one to probe local regions of the hadron's wave structure — individual segments or half-waves.

Helicity as a manifestation of internal dynamics: As noted earlier, states with an odd number of nodes (in particular, the neutrino with n=1) are characterized by internal dynamics — a directed redistribution of energy inside the wave structure. This may manifest as helicity — the orientation of the internal energy motion relative to the direction of particle propagation. Within this interpretation, the neutrino and antineutrino can be regarded as states with opposite orientation of this internal dynamics, which is consistent with the observed differences in their helicity.

Selectivity of interaction: When interacting with a hadron, the local structure of the wave probe enters into resonant interaction with specific segments of the hadron's internal structure. Experimentally, it is established that neutrinos and antineutrinos interact differently with hadron components. Within the proposed model, this may be related to the fact that different segments of the wave structure (corresponding to different "quark" components) possess different phase and energy configurations. Depending on the orientation of the probe's internal dynamics (helicity), a preferential interaction occurs with those regions of the structure for which the condition of greatest consistency (resonance) is satisfied.

Physical interpretation of the process: The interaction leads to a local restructuring of the hadron's wave structure, accompanied by a redistribution of energy and subsequent hadronization. As a result, characteristic jets of particles are observed, corresponding to the decay of the original structure into new stable configurations.

Thus, the observed selectivity of the interaction of neutrinos and antineutrinos can be interpreted as a consequence of the different orientation of their internal wave dynamics and its matching with the internal structure of the hadron. In this sense, the mathematical selection rules used in the standard theory can be regarded as a reflection of a deeper wave mechanism.

A slightly different, more intuitive interpretation:

Helicity as a manifestation of internal rotation: *As shown in Section 7.3.1, the neutrino (n=1) is a particle with an odd number of nodes and, consequently, possesses internal dynamics — a directed redistribution of energy inside the wave structure. The direction of this process determines the helicity of the particle — the projection of its spin onto the direction of momentum. For the neutrino, the spin is opposite to the momentum (left-handed helicity); for the antineutrino, it is along the momentum (right-handed helicity). Thus, the difference between them can be interpreted as a difference in the direction of internal rotation.*

In an intuitive picture, such dynamics can be described as the formation of a kind of "funnel" of energy distribution along the direction of motion. For left-handed helicity (neutrino), one can speak of a shift of the region of lower energy density forward and higher energy density backward. For right-handed helicity (antineutrino), the pattern is opposite.

When interacting with a hadron (e.g., a proton or neutron), the structure of the incident particle enters into resonant interaction with specific segments of the hadron's internal wave configuration. Experimentally, it is established that neutrinos and antineutrinos interact differently with hadron components. Within this interpretation, this can be related to the fact that different regions of the hadron's wave structure (conventionally corresponding to different "quark" components) possess different energy densities and phase configurations.

- *The neutrino (left-handed helicity) predominantly interacts with regions of lower energy density.*
- *The antineutrino (right-handed helicity) predominantly interacts with regions of higher energy density.*

In an intuitive model, this can be imagined as a process of local mutual compensation of energy density changes, in which the system tends toward a state with a smaller gradient. As a result, a restructuring of the hadron's wave structure (hadronization) occurs, accompanied by the emission of interaction products and the formation of jets.

Thus, the difference in the reactions of neutrinos and antineutrinos receives a clear physical explanation. The mathematical selection rules used in the standard theory can then be regarded as a reflection of this wave mechanism.

7.3.7.3 Quark Charges in the Proton and Neutron

7.3.7.3.1 Geometry of the Proton in Cross-Section

According to the wave model, the proton corresponds to a standing wave configuration with four nodes, which leads to the formation of five half-waves. These half-waves represent regions of alternating increase and decrease in energy density relative to some average level.

In three-dimensional space, such a structure can be approximately described as a radial standing wave in which the energy density depends primarily on the distance from the particle's center. In this case, regions of different density sign form a system of nested spherical shells.

To analyze the interaction of a probe with the internal structure of the proton, it is convenient to consider a planar cross-section of this three-dimensional configuration. In such a cross-section, the spherical shells appear as concentric annular regions.

As a result, the cross-section of the proton can be represented as a circle of radius RR, inside which regions with alternating signs of energy density are located:

$$+ \quad - \quad + \quad - \quad +$$

where the "+" sign denotes a region of increased energy density, and the "−" sign denotes a region of decreased energy density relative to the average level.

The center of the circle corresponds to the maximum energy density of the central half-wave. As one moves away from the center, there is a sequential alternation of regions of increased and decreased density.

For a simplified geometric analysis, assume that the characteristic radial scale of each half-wave is approximately the same. In this approximation, the particle diameter D can be represented as the sum of five equal intervals:

$$\mathrm{d} = \frac{D}{5}$$

Then the characteristic radii of the region boundaries can be given as:

$$r_1 = \frac{d}{2}, \qquad r_2 = \frac{3d}{2}, \quad r_3 = \frac{5d}{2} = \frac{D}{2}$$

These radii define a sequence of concentric regions corresponding to different phases of the wave structure.

It should be emphasized that this scheme is a simplified geometric representation of the three-dimensional wave configuration. It does not claim to be an exact description of the energy density distribution, but is used as a tool for estimating the relative contributions of different regions when interacting with an external probe.

7.3.7.3.2 Areas of the Annular Regions

In the previous section, the cross-section of the proton was represented as a system of concentric regions with alternating increased and decreased energy density, corresponding to the half-waves of the standing structure.

Consider the interaction of a probe (e.g., a neutrino or antineutrino) with such a structure. In deep inelastic scattering processes, the probe interacts with local regions of the particle's internal configuration. The probability of interaction is determined both by the characteristics of the region itself and by its geometric size.

In general form, the interaction probability can be represented as an integral over the cross-sectional area:

$$\mathbf{P} \propto \int \rho_{int}(x)dS$$

where $\rho_{int}(x)$ is the effective interaction density, and dS is an area element.

In the approximation where the interaction density within a given region does not vary significantly, the interaction probability can be considered proportional to the area of the corresponding region:

$$P \propto S$$

Thus, the relative probabilities of probe interaction with different parts of the structure can be estimated through the areas of the corresponding annular regions.

Within the simplified geometric model introduced earlier, the radial structure of the proton is given by a sequence of half-waves of equal characteristic scale dd. Then the boundaries of the regions are determined by the radii:

$$r_1 = \frac{d}{2}, \qquad r_2 = \frac{3d}{2}, \;\; r_3 = \frac{5d}{2}$$

The central region has radius r1r1, and the subsequent regions form rings between the corresponding radii.

The areas of these regions are:

Central region:

$$S_1 = \pi r_1^2 = \pi \left(\frac{d}{2}\right)^2 = \frac{\pi d^2}{4}$$

First ring:

$$S_2 = \pi(r_2^2 - r_1^2) = \pi\left(\left(\frac{3d}{2}\right)^2 - \left(\frac{d}{2}\right)^2\right) = \pi\left(\frac{9d^2}{4} - \frac{d^2}{4}\right) = \pi\frac{8d^2}{4} = 2\pi d^2$$

Second ring:

$$S_3 = \pi(r_3^2 - r_2^2) = \pi\left(\left(\frac{5d}{2}\right)^2 - \left(\frac{3d}{2}\right)^2\right) = \pi\left(\frac{25d^2}{4} - \frac{9d^2}{4}\right) = \pi\frac{16d^2}{4} = 4\pi d^2$$

Total area:

$$S_{sum} = S_1 + S_2 + S_3 = \pi \mathrm{d}^2\left(\frac{1}{4} + 2 + 4\right) = \pi \mathrm{d}^2\frac{25}{4} = \frac{\pi \mathrm{D}^2}{4}$$

which corresponds to the area of a circle of radius D/2D/2, as it should.

The obtained values determine the relative fractions of the cross-section attributable to different regions of the wave structure. Accordingly, they determine the probabilities that the probe, upon interaction, will be in a region with a given energy density.

These estimates can be compared with the results of deep inelastic scattering experiments, where different contributions from the internal components of the proton are observed.

It should be emphasized that this scheme represents an approximate geometric model of the cross-section and is used primarily for estimating the relative contributions of different regions.

7.3.7.3.3 Distribution of Signs and Interaction Probabilities

Within the framework of the wave model, regions with different energy densities may participate differently in interactions with particles possessing different helicities.

In particular, the following interpretation can be considered:

- Regions of increased energy density (conventionally "positive" half-waves) predominantly participate in interactions with the antineutrino (right-handed helicity);
- Regions of decreased energy density (conventionally "negative" half-waves) predominantly participate in interactions with the neutrino (left-handed helicity).

In the geometric model of the proton cross-section used here:

- The central region and the outer ring (S_1 and S_3) correspond to increased energy density;
- The intermediate ring (S_2) corresponds to decreased energy density.

Then the effective area for interaction with the antineutrino can be estimated as:

$$S_{\text{anti}} = S_1 + S_3 = \frac{\pi \mathrm{d}^2}{4} + 4\pi \mathrm{d}^2 = \frac{17}{4}\pi \mathrm{d}^2$$

For the neutrino:

$$S_{\text{нейтр}} = S_2 = 2\pi \mathrm{d}^2$$

Assuming that the interaction probability is proportional to the area of the corresponding region, we obtain:

$$P_{\text{anti}} = \frac{S_{\text{anti}}}{S_{sum}} = \frac{17/4}{25/4} = \frac{17}{25} = 0.68$$

$$P_{\text{neutr}} = \frac{S_{\text{neutr}}}{S_{sum}} = \frac{2}{25/4} = \frac{8}{25} = 0.32$$

Thus, the model yields a difference in interaction probabilities related to the internal structure of the proton and the nature of the energy density distribution.

It should be noted that this estimate is based on a simplified geometric model and the assumption of uniform interaction density within each region. Nevertheless, it demonstrates that differences in the behavior of neutrinos and antineutrinos may be associated with the geometry and internal structure of the hadron.

In a more precise treatment, additional factors such as the energy density distribution within the regions and the interaction dynamics must be taken into account; however, the proposed scheme provides a qualitative and quantitative estimate of the effect.

7.3.7.3.4 Comparison with Experimental Data

In deep inelastic scattering experiments, characteristic jet charge values are observed, which in the Standard Model are interpreted as contributions from quarks.

In particular, in an early experiment (1979, Fermilab), the following results were obtained:

- For reactions with neutrinos (when a **u-quark** is knocked out), the average jet charge was: Q=+0.65±0.12.
- For reactions with antineutrinos (when a **d-quark** is knocked out), the average jet charge was: Q=−0.33±0.09.

Within experimental errors, these values are close to the fractional quark charges:

$$+\frac{2}{3}, \qquad -\frac{1}{3}$$

In the Standard Model, these results are interpreted as interactions with u- and d-quarks.

Within the wave model, an alternative interpretation of the origin of these contributions can be proposed.

If the interaction of the probe with the internal structure of the proton is considered as a random hit into one of the regions of the cross-section, then the probability of interaction with a given region is determined by its geometric contribution. In this case, the relative interaction probabilities are related to the area distribution of regions with different energy densities.

In the geometric model used, three regions correspond to increased energy density, and two regions correspond to decreased energy density. This distribution leads to two characteristic interaction fractions — a larger one and a smaller one — which in order of magnitude are close to the ratios

$$\frac{2}{3}, \qquad \frac{1}{3}$$

Thus, the fractional charge values observed in experiments can be interpreted as a manifestation of the geometric structure of the standing wave inside the proton.

In this interpretation, quarks are not considered as point-like fundamental objects but appear as effective interaction regions arising from the energy density distribution inside the wave structure.

In particular:

- Regions of decreased energy density may correspond to an effective contribution of order $-\frac{1}{3}$;
- Regions of increased energy density may correspond to contributions of order $+\frac{2}{3}$.

In this case, the quark composition of the proton

$$uud$$

can be regarded as an effective description of the internal wave structure consisting of five half-waves with alternating energy density distribution.

Reasons for possible discrepancies between the model and experiment:

The obtained estimates are approximate and may differ from experimental values for a number of reasons:

1. **Angular effects.** The direction of the probe's momentum does not always coincide with the radial structure, which changes the effective interaction region.
2. **Interaction dynamics.** The efficiency of energy transfer depends on the local density and may enhance the contribution of denser regions.
3. **Detection features.** Detector limitations (aperture, sensitivity thresholds) affect the statistics of observed events.
4. **Probe energy.** The effective size of the probe is determined by its de Broglie wavelength. As the probe energy increases, the interaction becomes more localized, allowing individual structural elements to be resolved. At lower energies, averaging over several regions occurs, leading to deviations in the observed values.

Thus, the difference between the calculated and experimental values may reflect the degree of interaction localization and serve as an indicator of the depth of inelastic scattering.

7.3.8 Summary: Wave Interpretation of the Structure of Elementary Particles

The results considered in this section allow us to formulate a generalized representation of elementary particles within the framework of the wave model.

Elementary particles can be regarded as stable standing wave structures characterized by the number of nodes nn. This number determines their basic physical properties — mass, characteristic size, and mode of interaction with the surrounding environment.

The key point here is the distinction between two types of internal organization:

- For odd ***n*** (neutrino, neutron), the presence of internal energy redistribution (rotation) is characteristic, which leads to the absence of electric charge;
- For even ***n*** (electron, proton), the structure becomes symmetric, allowing electric charge to manifest as a result of the boundary work of the wave configuration.

Thus, charge and internal dynamics appear as alternative ways of manifesting the same wave nature.

An important consequence of the model is that the size of a particle is determined by its entire standing wave structure, not by a point-like region. This allows the elementary particle to be considered as a physically extended object, whose interaction with external systems depends on the structure of the energy distribution inside it.

In this context, the concept of "point-likeness" used in quantum mechanics may be associated with a region of informational opacity, whereas the observed behavior of the particle is described by its wave configuration.

Using the proton as an example, it has been shown that the internal structure of a standing wave can be interpreted as a system of regions with different energy densities. The geometric distribution of these regions determines the probabilities of interaction with an external probe.

This, in turn, makes it possible to propose an interpretation of quarks as effective interaction regions arising from the structure of half-waves, and of the observed fractional charges as a result of the geometric distribution of contributions inside the wave configuration.

Thus, the wave model allows one to connect:

- the geometry of the standing wave,
- the internal structure of the particle,
- the interaction probabilities,
- and the observed characteristics in experiments, within a unified description.

The obtained results are qualitative and quantitative in nature and are based on simplified geometric assumptions. Nevertheless, they demonstrate that a number of properties of elementary particles can be interpreted as consequences of their wave structure.

Further development of the model requires refinement of the interaction dynamics and consideration of transitions between different levels of description, which will be discussed in subsequent sections.

7.4 The Nature of Elementary Particles in the Wave Model

The representation of elementary particles as standing waves makes it possible not only to describe their parameters but also to form visual images of their structure and interactions.

This section discusses qualitative interpretations that allow linking the geometry of wave configurations with the observable properties of particles. It should be emphasized that the following representations are illustrative in nature and do not replace a rigorous mathematical description, but rather complement it.

7.4.1. Idealised Model: Spherical Wave with Internal Structure

In the simplest, idealized representation, an elementary particle (within the framework of the postulate on the wave nature of matter) can be considered as a spherical wave structure.

Inside this structure, regions of increased and decreased energy density alternate, forming a system of half-waves that determine its internal organization. Such a structure reflects the concept of a particle as an extended wave configuration rather than a localized point-like object.

In an intuitive approximation, such a structure can be imagined as an elastic object undergoing complex volumetric oscillations (for example, an analog of an elastic ball with internal wave dynamics). It should be emphasized that this analogy is illustrative and is used solely for intuitive understanding of the structure.

For neutral particles (with an odd number of nodes n, such as the neutrino and neutron), in addition to the radial distribution of energy density, they are characterized by the presence of internal rotation or "twisting" of energy density along some axis. This property is associated with their wave configuration and was discussed in Section 7.3.

7.4.2. The Real Particle: Interaction with the Medium, Spin, and Forces

In real conditions, the idealized spherical form of a particle's wave structure is inevitably distorted.

- The formation of a particle as a wave formation is accompanied by changes in the energy density of the surrounding environment (Postulate 1).
- Since a particle has a finite spatial scale, its wave boundary interacts with the surrounding environment, leading to local deformations and asymmetry of the structure.

- The resulting dynamic distortions and asymmetry of the wave configuration can be considered in this model as one possible mechanism for the formation of spin properties. In this interpretation, spin is not seen as an initially given abstract quantity, but as a characteristic related to the geometry and internal dynamics of the wave structure. In particular, the difference in the nature of internal deformations and energy distribution may lead to different manifestations of spin at different scale levels. It should be noted that this mechanism is not the only possible one and requires further analysis.
- The asymmetry of shape and energy distribution also leads to the emergence of directed interactions between particles, which within the framework of the model can be considered as a manifestation of the resonant matching of their wave structures.

7.4.3. Manifestation of the Work of Space: Charge and Internal Rotation

Within the framework of the proposed model, it is assumed that the formation of a standing wave structure is associated with the work performed by the energy medium during the formation of each half-wave. A detailed discussion of this principle is given in Section 7.6; here it is used at the level of qualitative interpretation.

If we proceed from the assumption that such work is invariant for individual half-waves, then the different ways in which it manifests itself in the particle's structure can lead to observable physical properties. In particular, the model distinguishes two characteristic regimes:

- **Charged particles (n even, e.g., electron and proton):** The work of space manifests itself in the form of a stable energy density gradient at the boundary of the wave structure. Such a gradient can be interpreted as an electric charge. In this case, the quantization of charge is associated with the invariant nature of the work expended in forming the boundary half-wave.
- **Neutral particles (n odd, e.g., neutrino and neutron):** In these cases, the work of space manifests itself primarily in the internal organization of the structure — in the form of rotation or "twisting" of the energy distribution. Such internal rotation does not lead to the formation of an external density gradient and, accordingly, does not manifest as an electric charge.

Thus, within the model, charge and internal energy rotation can be regarded as different forms of manifestation of the same process — the formation and maintenance of the particle's wave structure.

Additional remark on the interaction of neutral particles

For particles with an odd number of nodes, which possess internal energy rotation, the interaction may be more complex in nature compared to charged particles.

When interacting with charged objects, the internal dynamics of energy distribution can lead to an effective "drawing" of the particle into the interaction region, which is associated with the redistribution of energy density in the surrounding environment.

The interaction between neutral particles themselves may then depend on the mutual orientation of their internal dynamic structures. Within the framework of the model, this allows for both effective attraction and repulsion, analogous to the behavior of systems with internal moments (e.g., magnetic dipoles).

Such a dependence on the interaction configuration can lead to additional energy contributions, which in experiments manifest as a change in the effective characteristics of particles, including their measured mass.

7.4.4. Particle Mass: A Dynamic Characteristic and the Influence of Internal Rotation

Within the framework of the wave model, the mass of a particle is associated with the energy distribution in its standing wave structure. The amplitude of the longitudinal component of the wave, M_0, serves as a basic characteristic that determines the local energy density.

However, the observed mass is not reduced to the value of the amplitude in a single region. It is determined by the complete configuration of the wave structure and can be considered as an effective quantity that depends both on the amplitude and on the geometry and distribution of half-waves in space.

When the state of motion of a particle changes, its wave configuration (characteristic size, wavelength λ_0) changes. Within the assumption of the invariance of the work associated with the formation of half-waves, this leads to a redistribution of energy inside the structure and, consequently, to a change in effective mass.

For neutral particles with an odd number of nodes, the internal dynamics of energy distribution, manifesting as rotation or "twisting" of the structure, plays a significant role. The energy of such internal motion contributes additionally to the observed characteristics of the particle.

Depending on the interaction conditions, this contribution can manifest itself differently. When interacting with external fields or charged particles, it can yield an effective uniform change in energy, whereas when neutral particles interact with each other, both enhancing and compensating effects are possible, depending on the mutual orientation of their internal structures.

In experimental conditions where observed characteristics are determined by averaging over different interaction configurations, such contributions can manifest as an additional component of effective mass.

Thus, the difference between the "geometric" mass associated with the standing wave amplitude and the experimentally observed mass may be due to the contribution of the internal dynamics of the wave structure. In particular, this can lead to deviations from simple dependencies based only on the number of nodes and requires consideration of additional factors (see Section 7.7).

Overall, mass in this model is considered as an integral characteristic of the wave structure, reflecting both its geometry and internal dynamics, as well as the conditions of interaction with the surrounding environment.

7.5 Interference of Standing Waves (Particles)

Methodological note: invariance of work and the role of resonance

In classical physics, stable standing waves are usually considered as the result of imposing boundary conditions in a confined space (e.g., in a resonator).

The proposed model uses a different interpretation. The confinement of the wave structure is set not by external geometric boundaries, but by the conditions of resonant matching in an energy-saturated medium.

This means that the stability of a standing wave is determined not by the "presence of boundaries," but by the possibility of a self-consistent energy distribution at a given interaction speed.

Within this approach, the concept of invariant work associated with the formation of each half-wave of a standing structure is introduced. This work is determined by the resonance conditions and is assumed to be the same for all stable elementary configurations.

Such a representation is consistent with the approach outlined in the work "The Birth of Dimensions" https://zenodo.org/records/19380194, where physical quantities are considered as different levels of description of a single process, and their interrelation is nonlinear.

In this context:

- the "confinement" of the wave arises as a consequence of resonance,
- and the "work of space" is interpreted as the energy required to form and maintain a stable wave configuration.

This allows mass, charge, and other characteristics to be considered as derivatives of a single invariant process of wave structure formation.

7.5.1 General principles of interaction of wave structures

Within the framework of this model, elementary particles are considered as stable standing wave configurations (Postulate 2), formed in an energy-saturated medium (Postulate 1) and maintained through the resonant matching of their internal parameters (Postulate 3).

Such a wave structure is not a localized point, but represents an extended formation with a distributed energy density. The stability of this structure is ensured by a balance between the wave geometry, its dynamics, and the conditions of interaction with the medium.

In contrast to the classical representation of particles as solid objects, interaction in this model is not reduced to mechanical collision or penetration. Direct superposition of two stable standing waves without changing their internal structure is difficult, since each of them is a self-consistent configuration that requires certain conditions for its existence.

The interaction between particles in this case is realized as a process of energy redistribution in the medium, leading to a change in their wave configurations. This process is determined by the invariant work associated with the formation and maintenance of standing waves.

The system as a whole tends toward states in which the total work required to maintain the configuration is minimal. This manifests itself in the form of observable force interactions:

- the approach of systems that leads to a decrease in total work is realized as attraction;
- configurations requiring additional work manifest themselves as repulsion;
- for structures with internal dynamics (e.g., internal energy rotation), the nature of the interaction may depend on the mutual orientation of their configurations.

Thus, the interaction of particles in this model is not a local act of collision, but a process of matching wave structures through the medium in which they exist.

This representation is key to understanding the phenomenon of interference, which is considered further as a special case of such matching under conditions of weakened direct interactions.

7.5.2 Conditions for the emergence of interference

Interference effects do not manifest under just any conditions of interaction of wave structures, but rather in special regimes where direct force interactions between particles and the medium are weakened or of secondary importance.

Under ordinary conditions, particle interaction is determined by the redistribution of energy between their wave structures and is accompanied by significant changes in configuration. However, in situations where the interaction is weak or limited, the resonant properties of the wave structures themselves come to the fore.

Such conditions include, in particular:

- the passage of particles through narrow slits;
- interaction with thin boundaries or surfaces;
- rarefied particle fluxes, in which their mutual influence is minimal.

In these cases, the wave structure of the particle is not destroyed, but undergoes deformation due to the boundary conditions of the medium. Slits or obstacles act not as solid barriers in the classical sense, but as regions that change the conditions of resonant matching.

If the characteristic size of the obstacle becomes comparable to the particle's wavelength, its wave structure cannot maintain its original configuration and is forced to rearrange in accordance with the new conditions. This leads to the appearance of multiple allowed propagation states after passing the obstacle.

It is important to note that under these conditions, the behavior of the particle is determined not by a single trajectory, but by a set of possible configurations, each corresponding to a specific way of matching the wave structure with the surrounding environment.

Thus, interference arises in those regimes where:

- the wave structure of the particle is preserved during interaction;
- the boundary conditions of the medium significantly affect its configuration;
- the system allows several stable or quasi-stable propagation regimes.

These conditions lay the foundation for the formation of an interference pattern, which is further considered as a result of the resonant selection of allowed states.

Intuitive interpretation of interaction with a slit

For a visual understanding of the interaction of a particle's wave structure with the boundaries of a slit, a simplified analogy can be used.

The particle and the edges of the slit can be imagined as structures with a certain "internal geometry." When passing through the slit, their interaction resembles the contact of uneven surfaces or the interlocking of complex shapes, similar to how elements with a toothed structure interact.

As a result of such interaction, the wave configuration of the particle changes, leading to a spread in the directions of its further propagation.

However, this analogy is only illustrative. Unlike mechanical interlocking, the actual process is determined by the resonant matching of the particle's wave structure with the environmental conditions, which leads to the formation of an ordered interference pattern.

7.5.3 Interference as a result of resonant selection

In the classical description, interference is considered as a result of wave superposition, in which amplitudes are added taking into account phase relationships.

Within the framework of the proposed model, this phenomenon can be interpreted as a result of the resonant selection of allowed propagation configurations of a particle's wave structure in a medium.

After passing through a system of slits, the wave structure of the particle finds itself in conditions where there is not a single possible mode of further propagation, but many. These modes differ in phase characteristics and spatial configuration.

However, not all such states are stable. Propagation is primarily realized in those directions in which the particle's wave structure maintains coherence with the medium, i.e., is in a state of constructive resonance.

In directions where this coherence is disrupted, the wave structure cannot be maintained without additional energy expenditure, and the corresponding states are suppressed.

As a result, an alternating pattern of regions is observed on the screen:

- regions of increased hit density, corresponding to stable resonant configurations (interference maxima);
- regions of decreased hit density, corresponding to suppressed or mismatched states (interference minima).

Thus, the interference pattern arises not as a result of the superposition of independent waves, but as a consequence of the selection of stable propagation modes of the particle's wave structure under conditions defined by the boundary configurations of the medium.

In this case, the intensity distribution coincides with the results obtained within the framework of standard wave description, but receives a different physical interpretation.

7.5.4 Connection with the probabilistic description in quantum mechanics

In quantum mechanics, interference effects are described using the wave function, the squared modulus of which determines the probability of detecting a particle in a given region of space.

Within the framework of the proposed model, such a description can be interpreted as an effective way of accounting for the many possible propagation configurations of a particle's wave structure.

As shown above, after interacting with boundary conditions (e.g., slits), the particle does not move along a single trajectory but realizes a set of allowed propagation regimes determined by the conditions of resonant matching with the medium.

Each such regime corresponds to a certain probability of realization, depending on the degree of stability of the corresponding configuration.

In this context:

- the wave function can be considered as a mathematical representation of the set of possible states of the particle's wave structure;
- its squared modulus corresponds to the probability of realization of particular stable propagation configurations;
- the interference pattern reflects the distribution of these probabilities, determined by the resonance conditions.

Thus, the probabilistic description is not introduced as a fundamental property of the particle, but arises as a result of incomplete knowledge about the specific realized configuration of its wave structure and the conditions of its interaction with the medium.

At the same time, the mathematical apparatus of quantum mechanics remains applicable and correct, but receives an additional physical interpretation in terms of extended wave structures and their resonant interaction.

7.5.5 Conclusion

Thus, within the framework of the proposed model, interference effects are considered as a consequence of the resonant interaction of extended wave structures of particles with the energy medium and the boundary conditions set by the experimental configuration.

The observed interference pattern reflects the distribution of stable propagation regimes realized under given conditions and can be described using the standard mathematical apparatus of quantum mechanics.

The proposed approach does not change the results of calculations, but supplements them with a physical interpretation in which the behavior of particles is determined by their internal wave structure and the conditions of its matching with the medium.

Thus, interference receives an intuitive explanation as a special case of the general principle of resonant interaction of wave configurations.

7.6 Work as the Basis of Charge: A Geometrical Interpretation

In the previous sections, it has been shown that, within the framework of the proposed model, elementary particles represent stable standing wave configurations (Postulate 2), formed in an energy-saturated medium (Postulate 1) and maintained through resonant matching (Postulate 3).

The formation of such a structure requires a redistribution of energy in the medium. This process can be characterized as the work associated with the creation and maintenance of the wave configuration.

As noted earlier, stable standing waves can be represented as a set of half-waves. Each such half-wave corresponds to an elementary act of structure formation and, accordingly, can be associated with a certain amount of work.

A key question arises:

Can this work be invariant in nature and be related to fundamental physical quantities, in particular — to the electric charge?

Within the framework of the proposed model, space is considered not as a passive geometric arena, but as an active energy-saturated medium in which wave processes occur (Postulate 1).

In this context, the following property is key:

space as a medium does not distinguish between the individual wave processes occurring within it.

In other words, if the formation of a standing wave is considered as a local process of energy redistribution, then from the point of view of the medium itself:

- there are no "privileged" regions,
- there are no "special" half-waves,
- there are no differences between identical acts of energy localization.

This property can be illustrated by an analogy with pressure in a fluid: in a homogeneous medium, the pressure on the walls of a spherical volume is the same in all directions, regardless of the choice of observation point.

Transferring this to the wave model:

each act of formation of an elementary part of a wave structure (a half-wave) must be accompanied by the same amount of work on the part of the medium.

If this were not the case, then:

- local energy imbalances would arise in the system,
- which would lead to a spontaneous redistribution of energy,
- and, ultimately, to a violation of the stability of the structure.

Thus, the invariance of work per elementary act of wave formation is not an assumption, but a consequence of:

- the homogeneity of the medium,
- the absence of distinguished directions,
- and the law of conservation of energy.

7.6.1. Geometric nature of the invariant work of a half-wave

Consider a standing wave as a set of half-waves with characteristic wavelength λ_0 and amplitude M_0 describing the energy density distribution.

If we assume that the profile of one half-wave can be approximated by a sinusoidal function, then the amount of work associated with the formation of one half-wave can be estimated as an integral over its spatial profile:

$$S = \int_0^{\lambda_0/2} \mathrm{M}_0 \cdot sin\left(\frac{2\pi x}{\lambda}\right) dx = \frac{\mathrm{M}_0 \cdot \lambda_0}{\pi}$$

Within the framework of this model, this quantity is interpreted as the work W expended on the formation of one half-wave:

$$W = \frac{M_0 \lambda_0}{\pi}$$

Substituting the expressions for amplitude and wavelength obtained earlier (Section 7.1.3), we obtain:

$$\mathrm{W} \propto \mathrm{c}^{-5}$$

or, in numerical form:

$$W = 2c^{-5}$$

The obtained expression for the work per half-wave is not introduced arbitrarily, but follows from the geometric description of the elementary act of energy localization while preserving the invariance of work.

The invariance of W is primary, while the dependencies of M_0 and λ_0 are secondary.

It is important to emphasize that in this expression the dependence on the number of nodes n cancels out, indicating the invariant nature of this quantity within the model.

Thus, regardless of the specific configuration of the standing wave (number of nodes), each half-wave is formed with the same amount of work.

This property is key: it allows W to be considered as a fundamental characteristic of the process of wave structure formation, potentially related to observable physical quantities.

7.6.2 From invariant work to physical charge: the role of symmetry and the boundary of the structure

If we assume that the formation of each half-wave is accompanied by the same amount of work on the part of the energy medium, a fundamental question arises:

how can this work manifest itself in the external interaction of a particle?

The internal structure of a standing wave has a high degree of symmetry. The half-waves located inside the particle alternate in sign of energy density and, due to this symmetry, largely compensate for each other's contribution when considering external interaction. Such internal elements of the structure participate in the formation of the stability of the configuration but do not create a directional effect in the external space.

A different situation arises for the boundary region of the wave structure.

The boundary half-wave represents a transition between the localized wave configuration and the surrounding energy medium. In this region, the full symmetry of the structure is broken, since one side of the half-wave interacts with the internal part of the particle, while the other interacts directly with the medium.

As a result, it is precisely the boundary half-wave that becomes the element through which the invariant work expended on the formation of the structure can manifest itself in external interaction.

From this point of view, the electric charge can be interpreted as an effective manifestation of the invariant work localized at the boundary of the wave structure, where the full symmetry of the energy distribution is broken.

The sign of the charge is determined by the nature of the boundary transition:

- if a region of increased energy density relative to the medium is realized at the boundary, one sign of charge arises;
- if a region of decreased density, the opposite sign arises.

Thus, charge in this model is not an independent fundamental quantity, but arises as a consequence of the geometry and boundary conditions of the wave configuration while preserving the invariant work.

7.6.3 Directional manifestation of work and the effective magnitude of charge

Let us consider how the invariant work localized on the boundary half-wave manifests itself during the interaction of two particles.

In the absence of interaction, the wave structure of a particle can, in the first approximation, be considered as symmetric about its center. The work associated with the formation of the half-waves is distributed in all directions in space.

However, when two particles interact, the situation changes. In this case, a direction of interaction is distinguished — the line connecting the centers of their wave structures.

Along this direction, not the entire symmetric structure of work manifests itself, but only that part of it which is oriented toward the other particle. In other words, during the interaction, it is not the full spherically symmetric distribution that is realized, but rather its effective directional component.

This can be interpreted as follows:

- the boundary half-wave forms a distribution of work in all directions;
- in the presence of a second particle, a selection of the interaction direction occurs;
- only that part of the distribution that projects onto this direction participates in the external interaction.

Thus, the effective quantity determining the strength of the interaction is associated not with the total work, but with its directional component.

In the simplest symmetric case, such a directional component can be estimated as a fraction of the full distribution, which leads to a reduction in the effective value compared to the full geometric quantity.

It is important to emphasize that this reduction is not arbitrary, but reflects a geometric fact: when transitioning from an isotropic distribution to an interaction along a distinguished direction, only a part of the complete structure is taken into account.

Taking this into account, a quantity can be introduced that characterizes the effective geometric manifestation of charge, defined as the directional component of the invariant work localized on the boundary half-wave.

This quantity sets the scale of the interaction, but by itself is not yet the observable physical charge, since the actual interaction also depends on the properties of the medium in which the perturbation propagates.

7.6.4 The role of the medium and the physical meaning of the fine-structure constant

In the previous section, it was shown that the invariant work localized on the boundary half-wave can manifest itself in external interaction as a directional component. This quantity sets the geometric scale of the interaction, but by itself does not yet determine the observed value of the electric charge.

The reason for this is that the interaction between particles does not occur in a vacuum, but in an energy medium that possesses its own properties.

Within the framework of the proposed model, the propagation of the perturbation associated with the boundary half-wave and its effect on another particle is determined not only by the geometry of the structure, but also by the characteristics of the medium through which this interaction is realized.

From this point of view, a distinction can be introduced between:

- the **geometric magnitude of charge**, determined by the structure of the wave configuration and the invariant work;
- the **observed charge**, which characterizes the efficiency of the transfer of this interaction through the medium.

Such a distinction naturally leads to the introduction of a coefficient reflecting the properties of the medium and its influence on the interaction process.

In this model, this coefficient is identified with the fine-structure constant αα, which can be interpreted as a characteristic of the efficiency of the realization of the electromagnetic interaction in the energy medium.

Then the observed charge can be represented as:

$$e \sim q_{\mathbf{geom}} \cdot \alpha$$

where:

- $q_{\mathbf{geom}}$ is the quantity determined by the geometry of the wave structure and the invariant work;
- $\boldsymbol{\alpha}$ is a coefficient reflecting the properties of the medium and the degree of realization of the interaction.

In this interpretation, the fine-structure constant ceases to be a purely empirical number and acquires a physical meaning as a parameter of the medium, determining how effectively the geometrically given interaction manifests itself at the observable level.

It is important to emphasize that this approach does not require a change in the experimentally established values, but offers a different interpretation of their origin.

7.6.5 Space as a process and the nature of invariant work

The invariance of work introduced earlier can be understood not only as a consequence of the geometry of the wave structure, but also as a more general property of the energy medium itself.

Within the framework of this model, space is considered as a continuous process of energy redistribution, rather than as a passive geometric stage. Any localized wave structure in this approach represents a particular case of this general process.

This means that the formation of a standing wave is not a phenomenon external to the medium, but rather represents a local state of the medium itself, arising under certain conditions of resonant matching.

From this point of view, the individual elements of a wave structure (half-waves) cannot have different "costs" of formation. If the energy expended on the formation of individual parts of the structure differed, this would lead to internal imbalances, causing a redistribution of energy and the destruction of the stability of the configuration.

Thus, the invariance of work per elementary act of wave structure formation is a consequence of:

- the homogeneity of the energy medium;
- the absence of distinguished directions;
- and the general law of conservation of energy.

In other words, the medium "realizes" all local processes in the same way, because it is itself a continuous process that does not distinguish between individual acts of energy redistribution.

In this sense, the invariant work can be considered as a fundamental characteristic of the interaction of a wave structure with the medium, rather than as a particular property of a specific particle.

Such an approach makes it possible to connect the geometric description of wave configurations with the general laws of conservation, without introducing additional independent parameters.

7.6.6 Numerical estimate of the effective charge

After introducing the invariant work and its directional manifestation, we can proceed to estimate the characteristic scale of the electric charge.

Using the previously obtained expression for the invariant work of one half-wave:

$$W = 2c^{-5}$$

and relating it to the characteristic interaction volume of the order

$$V \sim \frac{\pi}{6} c^{-3},$$

we obtain the following estimate for the total geometric work density:

$$\rho_W \sim \frac{W}{V} \sim \frac{12}{\pi c^2}$$

As discussed above, it is not the full symmetric quantity that manifests itself in external interaction, but rather its directional component. In the simplest approximation, this yields an effective geometric quantity:

$$q_{geom} \sim \frac{6}{\pi c^2}$$

Substituting the numerical value of the speed of light in the SI system, we obtain:

$$q_{geom} \approx 2.125 \times 10^{-17}$$

If we further take into account that the observed electromagnetic interaction is realized through the medium with an efficiency characterized by the coefficient αα, then the observed value of the charge can be estimated as:

$$e_{calc} \sim q_{geom} \cdot \alpha$$

Using the experimental value

$$\alpha \approx \frac{1}{137.0361}$$

we obtain:

$$e_{calc} \approx 1.551 \times 10^{-19}$$

The experimentally measured value of the elementary charge is:

$$e_{exp} \approx 1.602 \times 10^{-19} \text{ Кл}$$

Thus, the obtained estimate turns out to be close to the observed value.

It should be emphasized that this agreement is not introduced as an initial assumption, but arises as a consequence of the chosen geometric interpretation of invariant work and its manifestation through the properties of the medium.

7.6.7 On the possible nature of the fine-structure constant

In the preceding reasoning, the fine-structure constant α was interpreted as a characteristic of the efficiency of the realization of the electromagnetic interaction in the energy medium.

However, the question of its fundamental nature remains open.

Within the framework of the proposed model, at least two limiting scenarios are possible:

1. **Local interpretation**

   In this case, α is determined by the properties of the energy medium, which depend on its state, for example, on the energy density or the gravitational background.

   One might then expect that when the conditions of the medium change (e.g., at different scales or in different gravitational potentials), the value of α may exhibit weak variability.

2. **Global interpretation**

   In this case, α is a characteristic of the very process of energy organization in space and does not depend on local conditions.

   This situation is analogous to the acceleration due to gravity in a uniform field, where the observed quantity is determined by the global configuration of the medium and does not depend on specific objects.

The second scenario leads to the fact that any attempts to detect variability of α in local experiments may yield no result, since possible changes will either be absent or be compensated by other effects.

7.6.8 Possibilities for experimental verification

Despite this uncertainty, the search for possible variability of α is of interest, as it allows one to distinguish between the local and global interpretations.

In particular, experiments aimed at revealing the dependence of the electromagnetic interaction on external conditions may be considered:

- changes in gravitational potential;
- changes in the density of the medium;
- comparison of different scale levels.

It must be taken into account that most physical systems are formed by the very same interactions that are being tested. This can lead to a partial or complete compensation of the effects, which significantly complicates their experimental detection.

Thus, the absence of observable variability is not a direct refutation of the model, but merely indicates the possible global nature of the parameter α.

7.7 The nature of mass in the wave model and its quantitative estimation

Within the framework of the proposed model, mass is not considered as an initially given property of matter. It arises as a characteristic of stable wave structures — standing configurations of energy in an energy-saturated medium (Postulates 1 and 2).

In this context, it is fundamentally important to distinguish between two levels of description:

- **structural mass**, associated with the amplitude and geometry of the standing wave;
- **observable mass**, which manifests itself in interactions and experimental measurements.

Structural mass is determined by the energy distribution inside the wave configuration. Observable mass, in turn, depends on how this structure manifests itself in external interaction, including features of symmetry, energy density distribution, and internal dynamics.

Despite the fact that a particle in this model represents an extended wave structure, in experiments its mass appears as a quantity concentrated at some effective point — the center of mass. Within the framework of the model, this can be interpreted as a result of the projection of the distributed structure onto the interaction level, rather than as an indication of the actual point-like nature of the object.

Thus, mass in the proposed approach is not a fundamental quantity, but a derived characteristic arising from the geometry, amplitude, and internal dynamics of the wave structure.

7.7.1 Mass as a characteristic of the wave configuration and invariance of work

As shown earlier, the basic amplitude of the longitudinal wave M_0 characterizes the level of local energy densification in the particle's structure.

Within the framework of this model, the amplitude is not an independent quantity but is related to the characteristic spatial scale of the wave structure λ_0. This relationship is determined by the invariance of the work performed by the energy medium during the formation of each half-wave:

$$W = \frac{M_0 \lambda_0}{\pi}$$

where ***W*** is an invariant quantity that does not depend on the number of nodes or the specific configuration of the standing wave.

This relationship reflects the fundamental interconnection between energy localization (amplitude) and its spatial distribution (wavelength). In other words, an increase in the degree of energy localization (increase in amplitude) is accompanied by a decrease in the characteristic size of the structure, and vice versa.

Thus, mass within the model cannot be considered as an independent parameter. It is determined through the amplitude of the wave configuration, which, in turn, is related to its geometry and scale.

This has an important consequence: when the conditions of a particle's existence change — for example, during its motion or interaction — its wave structure may change. However, the invariant work ***W*** is preserved, leading to a redistribution between amplitude and spatial scale.

Such a redistribution can be interpreted as a change in observable mass while preserving the fundamental energy characteristic of the structure. In particular, this provides a possibility to qualitatively explain relativistic effects as a consequence of the change in the wave structure configuration, rather than as a change in an "internal" property of the particle.

Thus, mass in this model appears as a manifestation of a specific state of the wave configuration, determined by the balance between amplitude and spatial scale while preserving the invariant work.

7.7.2 Mass of the electron (n=2)

The electron, corresponding to the configuration with n=2, represents one of the simplest and most symmetric stable wave structures within the framework of the model.

Its internal configuration is characterized by the presence of a central region of energy densification, which determines the main amplitude of the standing wave M_0. Peripheral elements of the structure are either absent or do not contribute significantly to the observable mass.

Due to the high degree of symmetry and energy localization, the contribution of the electron's wave structure to the observable mass manifests itself almost completely. In this case, there is no need to introduce additional correction factors related to energy redistribution or the geometry of the structure.

Thus, the observed mass of the electron can be directly identified with the basic amplitude of its wave configuration:

$$m_e = M_0 \ \ (n = 2)$$

An important clarification should be made regarding the units used.

Within the framework of this work, the main relationships are derived in dimensionless form, where physical quantities are expressed through numerical values of fundamental parameters (in particular, the speed of light c). This approach reflects the postulate on the parametric nature of physical quantities and allows one to focus on their internal interrelation.

When transitioning to numerical estimates, the SI system of units is used, in which the speed of light has the dimension m/s. In this case, the expressions for amplitude automatically acquire the dimension of mass, and the resulting values can be compared with experimental data in kilograms.

Thus, the obtained numerical values of mass should be considered as the result of the transition from the dimensionless description of the model to the specific system of units used in experimental physics.

Substituting the value n=2 into the expression for the basic amplitude, we obtain:

$$\mathrm{M_0} \approx 9.144 \times 10^{-31} \text{ кг}$$

The experimentally measured mass of the electron is:

$$m_e^{\text{эксп}} \approx 9.109 \times 10^{-31} \text{ кг}$$

Thus, the calculated value turns out to be close to the experimental one, which can be considered as an important confirmation that in the case of the electron, the mass is indeed determined by the basic amplitude of the standing wave without the need to introduce additional structural corrections.

7.7.3. Calculation of Proton Mass (n=4)

The proton, corresponding to the configuration with n=4, represents a more complex wave structure compared to the electron. Its configuration includes not only a central region of energy densification but also additional peripheral regions that form a spatially distributed structure.

The central region, as in the case of the electron, sets the basic amplitude M_0 and makes the main contribution to the structural mass of the particle.

Unlike the electron, the proton possesses additional regions of increased energy density, located symmetrically with respect to the center. These regions are distributed elements of the structure, whose contribution to the observed mass is determined not only by their amplitude but also by the nature of their spatial arrangement and symmetry.

Since the peripheral regions are distributed relative to the center, their contribution to the external interaction manifests itself effectively rather than fully. Taking into account the symmetry of the structure and the energy distribution, the total contribution of these regions can be estimated as a fraction of their full amplitude.

As a result, the observed mass of the proton can be represented as:

$$\mathrm{m_p} \approx \frac{2}{3}\mathrm{M_0}$$

where M_0 is the basic amplitude for the corresponding wave configuration.

Substituting the numerical value, we obtain:

$$\mathrm{M_0(n = 4)} \approx 1.078 \times 10^{-27} \text{ кг}$$

$$m_p^{calc} \approx 1.617 \times 10^{-27} \text{ кг}$$

The experimentally measured mass of the proton is:

$$m_p^{exp} \approx 1.673 \times 10^{-27} \text{ кг}$$

Thus, the calculated value turns out to be close to the experimental one, which indicates the correctness of taking into account both the central and distributed structure of the proton within the framework of the proposed model.

Attention should be paid to an interesting correspondence that arises when comparing the obtained coefficient with the results of the analysis of the proton's internal structure.

In previous sections (7.3.7), it was shown that when considering the cross-section of the proton as a system of concentric regions with different energy densities, the relative probabilities of a probe interacting with these regions naturally lead to fractions close to 2/3 and 1/3, which are interpreted as effective quark contributions.

In this section, the proton mass is expressed through the coefficient 3/2, which reflects the total contribution of the central and peripheral structure.

These results can be considered as two different manifestations of the same geometric organization of the wave structure:

- in the analysis of interactions (deep inelastic scattering), the distribution over the cross-sectional area manifests itself;
- in the determination of mass, the integral contribution of the entire structure, taking into account its symmetry and spatial distribution, manifests itself.

From this point of view, the coefficients 3/2 and 2/3 are not independent, but reflect different ways of "projecting" one and the same internal structure onto observable physical quantities.

7.7.4 Mass of the neutron (n=3) and the role of internal rotation

The neutron, corresponding to the configuration with n=3, differs fundamentally from the electron and the proton in that it possesses internal rotation of energy. This is due to the odd number of nodes and leads to an asymmetry of the wave structure.

Unlike the proton, where the structure is overall symmetric, the neutron is characterized by a more complex energy density distribution, in which the central and peripheral regions do not contribute equally to the external manifestation.

If only the geometry of the standing wave is considered, without taking into account the rotational dynamics, the structural mass contribution can be estimated as:

$$\mathrm{m}_{\mathrm{struct}} \sim \frac{3}{2}\mathrm{M}_0 \quad (\mathrm{n} = 3)$$

where M_0 is the basic amplitude for this configuration.

However, the experimentally measured mass of the neutron significantly exceeds this value. Within the framework of the proposed model, this indicates the presence of an additional contribution associated with the internal rotation of energy.

Internal rotation does not lead to an increase in local amplitude, but creates an additional dynamic component of energy that manifests itself in mass measurements. In other words, part of the neutron's energy is "hidden" not in the static configuration but in its internal motion.

To account for this effect, a coefficient can be introduced that characterizes the transition from structural mass to observable mass:

$$m_n \sim m_{struct} \cdot k$$

where ***k*** reflects the contribution of internal dynamics.

At the current stage, the model does not allow a rigorous derivation of the value of the coefficient ***k***. Its precise determination requires further development of the theory, in particular a more detailed description of the mechanisms of internal energy rotation and its contribution to the observed mass.

Nevertheless, within the framework of the proposed model, the coefficient ***k*** can be interpreted as a parameter of the transition from a structural regime to a dynamic regime of manifestation of the wave configuration.

In the structural regime, mass is determined mainly by the geometry of the standing wave and the distribution of its half-waves. However, in the presence of internal rotation, the system ceases to be purely static: part of the energy begins to manifest itself as an internal excitation of the structure.

From this point of view, the neutron should be considered not simply as an asymmetric standing wave, but as a standing wave that is in an additional regime of dynamic excitation. The coefficient ***k*** then reflects how strongly this internal excitation changes the observed manifestation of mass compared to a purely geometric configuration.

Since a characteristic scale factor

$$k = \left(\frac{c}{2\pi}\right)^{1/5} \approx 34.3343$$

was already introduced earlier in the model (Section 7.1.3), it is natural to assume that this same parameter may characterize the transition between two adjacent regimes of existence of a wave structure: from a statically organized configuration to a configuration with internal dynamics.

In this approximation, the observed mass of the neutron can be written as

$$m_n \sim m_{struct} \cdot k$$

where ***k*** acts as an excitation coefficient, rather than merely an external correction factor.

Numerically we obtain:

$$M_0(n = 3) \approx 3.142 \times 10^{-29} \text{ кг}$$

$$m_{struct} \approx \frac{3}{2} M_0 \approx 4.713 \times 10^{-29} \text{ кг}$$

$$m_n^{calc} \approx 1.618 \times 10^{-27} \text{ кг}$$

The experimentally measured mass of the neutron is:

$$m_n^{exp} \approx 1.675 \times 10^{-27} \text{ кг}$$

Thus, the observed mass can be interpreted as the sum of the structural contribution and the additional energy of internal rotation.

The coefficient $\boldsymbol{k}$ can be interpreted as a parameter of the transition between two regimes of existence of a wave structure: static (geometric) and dynamically excited. In this sense, it reflects not an external correction, but a change in the way mass manifests itself when internal energy rotation arises.

It should be emphasized that the exact nature of the coefficient $\boldsymbol{k}$ requires further analysis. It can be expected that this coefficient reflects the way in which the invariant work is redistributed between the structural and dynamic components of the wave configuration.

7.7.5 Features of the neutrino mass (n=1)

The neutrino, corresponding to the configuration with n=1, represents a limiting case among the particles under consideration. Its wave structure is characterized by the greatest extent and minimal amplitude.

Within the framework of the model, this means that the neutrino's energy is distributed over a substantially larger spatial scale compared to other particles. Unlike the electron, proton, and neutron, where a significant part of the energy is localized in a relatively compact region, in the neutrino this energy is "smeared" over space.

If only the basic amplitude is considered, the minimum mass estimate is given by:

$$M_0 \sim 2\pi c^{-4}$$

which yields a value on the order of:

$$m_{mod} \sim 10^{-32} \text{ kg}$$

However, experimental estimates of the neutrino mass are significantly lower and lie in the range:

$$m_\nu^{exp} \lesssim 10^{-36}\text{–}10^{-37} \text{ kg}$$

Within the framework of the proposed model, this discrepancy can be explained by a difference in scales.

The measurement of the neutrino mass is carried out in processes involving more localized structures — for example, nucleons. These structures set the characteristic interaction scale. As a result, the extended wave configuration of the neutrino is "projected" onto a substantially smaller scale corresponding to the sizes of other particles.

Such a mismatch of scales leads to the fact that the observed mass appears reduced compared to the model estimate. In other words, energy distributed over a large spatial interval is perceived as a smaller local quantity when measured.

Estimatively, this can be expressed as:

$$\mathrm{m_{obs}} \sim \frac{\mathrm{m_{mod}}}{\lambda_\nu/\lambda_\mathrm{p}}$$

where λν is the characteristic scale of the neutrino, and λp is the scale of the nucleon structure.

Substituting the corresponding values yields a quantity consistent with experimental constraints:

$$\lambda_n \approx 9{,}71 \times 10^{-11}$$

$$\lambda_p \approx 2{,}4 \times 10^{-15}$$

$$m_{\mathrm{obs}} \approx \frac{m_{\mathrm{mod}}}{\frac{\lambda_n}{\lambda_p}} = \frac{2{,}664 \times 10^{-32}}{4{,}048 \times 10^4} \approx 6{,}581 \times 10^{-37}$$

Thus, the small observed mass of the neutrino can be interpreted not as an absence of energy, but as a consequence of its distribution over a large scale.

This is consistent with the general idea of the model, according to which mass is determined not only by amplitude but also by the degree of localization of energy in space.

7.7.6 Antimatter and features of gravitational manifestation

Within the framework of the proposed model, antimatter can be considered as a wave structure possessing a configuration opposite in sign of the energy density distribution relative to ordinary matter.

If for particles of matter a central region of increased energy density, which forms an attractive gravitational manifestation, is characteristic, then for antimatter one can assume the opposite configuration, in which the central region corresponds to a decreased density.

From this point of view, gravitational behavior may depend not only on the total energy of the system, but also on the nature of its spatial distribution.

This allows for the possibility that antimatter may exhibit differences in gravitational interaction related to the features of its internal wave structure.

It should be emphasized that to date, experimental data do not provide unambiguous confirmation of differences in the gravitational behavior of matter and antimatter. Existing experiments indicate the similarity of their behavior in a gravitational field, but the accuracy of these measurements remains limited.

Within the framework of this model, this may mean that:

- either differences are indeed absent and gravity is determined only by the total energy of the system;
- or possible differences lie at a level not exceeding the current sensitivity of experiments;
- or they manifest only in certain regimes related to the internal dynamics of the structure.

From this point of view, the question of the gravitational behavior of antimatter remains open.

At the same time, the proposed interpretation allows a fresh look at the problem of the baryon asymmetry of the Universe.

If matter and antimatter have differences in the way they interact with the energy medium, this may lead not to a violation of the law of energy conservation, but to different scenarios of their spatial distribution and evolution.

In particular, a situation is possible in which antimatter does not disappear, but manifests itself in regimes or scales different from the observed baryonic matter.

Thus, the observed asymmetry may be related not to a violation of fundamental laws, but to the features of the manifestation of wave structures at different levels of description.

The role of the medium and the global energy distribution

Within the framework of the proposed model, the birth of a particle and an antiparticle is considered as a symmetric process of the formation of two wave structures with opposite configurations of energy distribution.

Such a pair as a whole does not create a directed perturbation of the energy medium: their contribution is mutually compensated at the level of the global energy distribution. In this sense, a particle–antiparticle system can be considered as a locally balanced configuration.

It is important to emphasize that the interaction between a particle and an antiparticle upon their approach is preserved and can lead to annihilation. However, at the level of their influence on the medium on large scales, their joint presence does not define a distinguished direction of change.

In contrast, matter possesses the ability for collective ordering — the formation of stable structures (atoms, stars, galaxies). Such ordering leads to a local change in the energy distribution of the medium.

Within the model, this can be interpreted as follows: it is not matter that directly "influences" antimatter, but rather the change introduced by matter into the energy medium affects all wave structures, including antimatter.

In other words, the interaction is realized not directly, but through a change in the properties of the medium.

From this point of view, the behavior of antimatter is determined not so much by local objects as by the global state of the energy medium. This makes its behavior sensitive to the integral characteristics of the system, rather than only to individual sources.

This picture, in its logic, is close to the interpretation of gravity as a manifestation of the global energy distribution, where the observed effects are determined not by individual bodies but by the entire configuration of the medium.

As a result, the direction and nature of the motion of antimatter may in general depend on the collective state of the medium and cannot be reduced to a simple interaction with a single macro-object.

Fractal interpretation of matter and antimatter

Within the framework of the fractal representation of the energy medium, an additional interpretation of the role of matter and antimatter can be proposed.

If the structure of space possesses a hierarchy of scale levels, then stable wave configurations can be considered as elements that ensure the redistribution of energy between these levels.

From this point of view, matter can be interpreted as a configuration aimed at localizing energy and its transition to smaller scales. As energy accumulates in the wave structure, the system reaches a threshold state at which a quantum transition to the next, deeper fractal level is possible.

Antimatter, in turn, can be considered as a configuration of the opposite type, associated with the redistribution of energy in the opposite direction — from deeper levels to larger scales.

In such an interpretation, matter and antimatter represent two complementary mechanisms of energy exchange between levels of the fractal structure. Their pair production reflects the need to maintain a balance of this exchange.

This allows the observed baryon asymmetry to be considered not as a violation of fundamental laws, but as a manifestation of the non-uniformity of the distribution of energy flows between scale levels, in which different regimes can dominate in different regions or at different stages of the system's evolution.

It should be emphasized that this interpretation is qualitative in nature and requires further development to obtain quantitative predictions.

7.7.7 Mass of extended systems and the role of internal dynamics

In the case of extended objects, such as galaxies, the measurement of mass is carried out by indirect methods — based on the dynamics of motion of their constituent objects (stars, gas) and on the gravitational influence on the surrounding environment.

Such estimates rely on observations of rotation velocities and matter distribution and are typically interpreted within the framework of gravitational interaction, assuming the presence of some effective mass of the system.

However, within the framework of the proposed model, an important clarification arises.

The observed mass of an extended system is determined not only by the localized mass of its constituents, but also by the complete energy configuration, including:

- the energy density distribution;
- the collective dynamics of the system;
- internal rotational and vortex processes.

This means that the observed mass may include a contribution associated with the internal motion of energy, similarly to what was shown for the neutron.

In particular, the rotation of a galaxy and the associated energy flows can create an additional contribution to the gravitational manifestation of the system, which, under the standard interpretation, is accounted for as "additional mass."

From this point of view, the difference between the "visible" mass of matter and the "dynamic" mass determined from rotation may be related not only to the presence of an unknown form of matter, but also to the features of the distribution and motion of energy within the system.

Thus, the observed effects traditionally interpreted as manifestations of dark matter may, within the framework of this model, be considered as a consequence of the internal dynamics of the wave structure of the system at a given scale level.

It should be emphasized that this interpretation does not exclude the existence of additional forms of matter, but shows that part of the observed effects can be explained without introducing them.

7.7.8 The role of energy density distribution in the formation of mass

Within the framework of the proposed model, the observed mass is determined by the energy density distribution in the wave structure of a particle or system.

Regions of increased energy density, where energy localization and concentration occur, play a key role. It is precisely such regions that form the main contribution to the gravitational manifestation.

Regions of decreased energy density, on the contrary, do not create an independent contribution to mass. However, they influence the geometry of the entire structure, altering the spatial distribution of energy.

In other words:

- regions of increased density form an active contribution to mass;
- regions of decreased density affect the distribution and configuration, but do not create "negative mass."

From this point of view, the observed mass is determined not only by the magnitude of the amplitude, but also by how the energy is distributed in space.

In particular, the presence of regions of decreased density can lead to a "smearing" of energy and a reduction in its effective localization, which affects the observed value of mass.

This approach is consistent with the general idea of the model, in which mass is a characteristic of the wave configuration, not a fundamental quantity.

It should be noted that within the framework of general relativity, the gravitational field is determined by the energy-momentum tensor, which takes into account the entire energy configuration of the system. The proposed interpretation does not contradict this approach, but clarifies that the contribution of different regions may manifest itself differently depending on their structure and distribution.

Connection with the phenomenon of dark energy

The considered principle of energy density distribution admits a broader interpretation that goes beyond individual particles or local systems.

If energy localization (the formation of regions of increased density) leads to the formation of mass and gravitational attraction, then the reverse process — the redistribution of energy with a decrease in local density — can manifest itself as a tendency to increase the characteristic distances in the system.

From this point of view, the processes of energy concentration and its "smearing" can be considered as complementary mechanisms ensuring the dynamic equilibrium of the energy medium.

On the scale of the Universe, this allows the observed accelerated expansion to be interpreted as a manifestation of a global redistribution of energy, opposite to the processes of gravitational localization.

In this approach, dark energy can be considered not as a separate entity, but as an effective manifestation of processes of decreasing energy density and the corresponding change in the geometry of space on large scales.

It should be emphasized that this interpretation is qualitative in nature and requires further development to obtain quantitative predictions and comparison with observational data.

7.7.9 Conclusion of the section

The consideration of mass within the framework of the wave model shows that it is not a fundamental quantity, but arises as a result of the organization of energy in space.

Depending on the structure of the wave configuration and the nature of its dynamics, mass can manifest itself in different ways:

- in the simplest cases (electron) — as a direct characteristic of the amplitude;
- in the presence of spatial structure (proton) — as a result of the geometric distribution of energy;
- in the presence of internal dynamics (neutron) — as the sum of structural and dynamic contributions;
- at large scales (neutrino) — as a quantity depending on the degree of energy localization;
- in extended systems (galaxies) — as an integral effect that includes collective dynamics.

Thus, mass in this model is determined not only by the amount of energy, but also by the way it is distributed and moves.

A key role is played by the invariance of work, which links the amplitude and spatial scale of the wave structure. This leads to the fact that a change in the conditions of existence of the system is accompanied not by a change in "internal" properties, but by a redistribution of energy within the structure.

This approach allows various physical phenomena — from elementary particles to cosmological effects — to be considered within the framework of a single principle based on the dynamics of energy distribution in space.

In particular, processes of energy localization manifest themselves as mass and gravity, while processes of its redistribution and decrease in density can lead to effects interpreted as the expansion of space.

Thus, mass, gravity, and cosmological effects can be considered as different manifestations of a single mechanism associated with the organization of energy in an energy-saturated medium.

8 Fractality of the Structure of the Universe

In the previous sections, a model of elementary particles was considered as stable standing wave configurations in an energy-saturated medium. The obtained relations connect the geometric characteristics of these structures with their energetic parameters and allow observable physical quantities to be interpreted as manifestations of internal wave dynamics.

However, this description applies to a fixed scale level and does not address the question of the interrelation between different levels of matter organization. Within the proposed approach, this issue is fundamental, since the model itself is based on the assumption of the fractal nature of physical processes.

In this chapter, the model is extended to the case of scale transitions, in which not only the observable parameters of systems change, but also the nature of their effective description.

Methodological foundation

The considered approach relies on the results presented in the work "The Emergence of Dimensions and the Perception of Fractality" (https://zenodo.org/records/19688973), where physical quantities are interpreted as derived characteristics of a unified wave process.

Within this interpretation:

- space, time, mass, and energy are not independent fundamental entities;
- they emerge as different levels of description of a process associated with the repetition and scaling of wave structures;
- the relationships between them are nonlinear and may be described through power-law dependencies.

A consequence of this approach is the rejection of treating dimensions as primary characteristics. In this chapter, as in the previous sections, a dimensionless representation of quantities is used, in which the physical meaning of relations is determined not by their dimensionality, but by the structure of their interconnections.

This does not imply abandoning the standard system of units, but indicates that it is derivative with respect to a more fundamental level of description.

Scale as a parameter of description

A key statement is that the physical parameters of a system (characteristic size, mass, frequency, and other quantities) are considered as parameters of the level of description rather than absolute properties of the object.

At a fixed level of observation, these parameters are invariant and define the observed physical picture. However, when transitioning to another scale level, they undergo transformations associated with changes in the nature of wave dynamics.

Thus, a distinction is introduced between:

- intra-level description, within which standard physical laws are preserved;
- and inter-level transitions, in which the very parameters defining these laws are altered.

Limitation of interaction transfer

In the previous sections, it was shown that the existence of stable wave structures requires a finite time for the coordination of their parts. This leads to a limitation on the speed of interaction propagation within the structure.

At this level of description, this limitation corresponds to the speed of light c, which is interpreted as the maximum speed of disturbance propagation in the medium.

It is important to emphasize that within the proposed model, this quantity is not treated as a universal absolute constant, but as a characteristic of a specific regime of wave-process synchronization.

In other words, the speed of light defines the boundary of stable interaction within a given scale level.

Transition to inter-level description

If a system is considered within a single level, the limitation on interaction speed leads to standard physical consequences, including causality and a finite signal propagation speed.

However, when transitioning between levels of description, the situation changes fundamentally. The following are modified:

- characteristic process frequencies,
- conditions of resonant synchronization,
- and effective parameters of the medium.

As a result, the limiting characteristics of interactions, including their propagation speed, may also change.

Therefore, the concept of a "limiting speed" loses its universal character and should be regarded as a parameter dependent on the level of description.

This statement is fundamental for further analysis and will be examined in detail in the subsequent subsections.

8.1 Scale Transition as a Transformation of System Parameters

The distinction introduced earlier between intra-level description and inter-level transitions requires formalization that allows one to describe how system parameters change under a shift of scale.

Within the framework of the considered model, it is assumed that the same physical process may have different effective descriptions depending on the level of observation. At the same time, a transition between levels does not imply a change in the physical essence itself, but rather reflects a change in the mode of its representation.

Let the state of a system at the level of description *n* be defined by a set of effective parameters:

$$P_n = \{L_n, \nu_n, M_n, \dots\}$$

where:

- L_n is the characteristic spatial scale,
- ν_n is the characteristic frequency of the process,
- M_n is the effective mass,
- and other parameters determine the observable dynamics.

The transition between levels of description n→n+1 can be formally represented as a transformation:

$$P_{n+1} = F(P_n)$$

where the operator ***F*** reflects the change in the scale of description.

Self-similarity property

The key assumption is that the operator ***F*** possesses the property of self-similarity, meaning that its functional form is preserved across transitions between levels.

This implies that the structure of relationships between parameters remains invariant, while the parameter values themselves change.

In particular, one may expect that the transition between levels is accompanied by a scaling transformation of the form:

$$L_{n+1} \sim \frac{L_n}{k}, \nu_{n+1} \sim \frac{\nu_n}{k}$$

where ***k*** is a characteristic scaling factor.

Such a relation reflects the natural connection between spatial and frequency scales: a decrease in characteristic size is accompanied by an increase in the frequency of the process.

Connection with the previously introduced model

The relations obtained in Section 7 for standing waves already demonstrate a similar dependence: an increase in the number of nodes leads to a decrease in the characteristic size and an increase in the energy-related parameter.

Thus, the model of elementary particles can be regarded as a particular case of a more general principle of scale transformation of parameters.

8.2 Constraint of Coherence and Characteristic Interaction Time

For any wave structure, the condition of coherence between its different parts is fundamental. This condition is determined by the time required for interaction to propagate within the system.

If the characteristic coherence time is denoted as Δt_n, then for a structure of size L_n, the following estimate holds:

$$L_n \sim c_n \Delta t_n$$

where c_n is the effective speed of interaction propagation at level $\boldsymbol{n}$.

This relation reflects the fact that interactions cannot propagate instantaneously, and the existence of a stable structure requires a finite time for information exchange between its parts.

Two-component structure of the process

As noted earlier, a wave process may be regarded as consisting of two interrelated components:

- a spatial component (associated with the extent of the structure),
- and an energetic component (associated with energy density and frequency).

Within a simplified representation, this leads to a constraint of the form:

$$c_n^2 = u_n^2 + v_n^2$$

where u_n^2 and v_n^2 characterize the contributions of different aspects of the wave process.

This relation should not be interpreted as a decomposition of velocity in the usual kinematic sense, but rather as a geometric expression of the balance between components that define the structure of the wave.

Physical meaning of the constraint

In this context, the quantity c_n defines the maximum speed at which coherence of the structure can be maintained at a given level.

If the size of the system exceeds the value corresponding to this constraint, its different parts cease to interact effectively, leading either to a loss of structural stability or to a transition into a different regime.

Thus, the limitation on the speed of interaction propagation is not an external postulate, but a consequence of the internal coherence of the wave process.

8.3 Interpretation of the Limiting Speed and Its Scale Dependence

In the previous section, the relation

$$L_n \sim c_n \Delta t_n$$

was introduced, where the quantity c_n characterizes the limiting speed of interaction propagation at level $\boldsymbol{n}$.

In the traditional approach, the speed of light is treated as a universal constant, identical for all processes. However, within the framework of the proposed model, such an interpretation requires refinement.

Limiting speed as a characteristic of the coherence regime

In the present approach, the quantity c_n is defined not as an abstract geometric property of space, but as a parameter that determines the conditions of coherence for wave processes in the medium.

This implies that:

- c_n characterizes the maximum speed of interaction transfer within stable structures at a given level;
- it is determined by the properties of the medium and the frequency characteristics of the processes;
- and therefore represents a parameter of effective description rather than an absolute universal quantity.

Thus, the speed of light ccc, as observed experimentally, corresponds to the value c_n for the level associated with baryonic matter and electromagnetic interactions.

Scale dependence of the limiting speed

When considering a transition between levels $n \to n+1$, as shown earlier, the following quantities change:

- characteristic sizes L_n,
- frequencies ν_n,
- and the structure of interactions.

Since the quantity c_n is defined through the relationship between these parameters, it may also change under a scale transition.

In the simplest form, this can be expressed as:

$$c_{n+1} = \alpha c_n$$

where α is a coefficient determined by changes in the properties of the medium and the structure of the wave process.

It is important to emphasize that this coefficient is not introduced arbitrarily, but reflects the change in coherence conditions when transitioning to another level of description.

Invariance within a level

Despite possible scale dependence, within a fixed level $\boldsymbol{n}$, the quantity c_n remains invariant.

This means that:

- all local physical processes are governed by the same limiting constraint;
- standard effects associated with finite interaction propagation speed are preserved;
- and known relations, including relativistic ones, remain valid.

Thus, the proposed interpretation does not contradict the observed physical laws at a given level, but rather refines the domain of their applicability.

8.4 Inter-Level Transitions and Changes in Interaction Conditions

Let us now examine in more detail what occurs during transitions between levels of description.

As shown earlier, a scale transition is accompanied by changes in the system parameters:

$$L_n \rightarrow L_{n+1}, \nu_n \rightarrow \nu_{n+1}, c_n \rightarrow c_{n+1}$$

However, this transition is not a simple rescaling within the same geometry. Rather, it reflects a change in the interaction regime of wave structures.

Change in frequency regime

Within the model, the transition to the next level is associated with a change in the characteristic frequency of the process:

$$\nu_{n+1} \sim k\nu_n$$

This implies that the system's dynamics accelerate or decelerate depending on the direction of the transition.

Since the conditions of coherence are determined by the relationship between frequency and interaction time, a change in frequency leads to a transformation of the entire dynamical structure.

Change in the effective medium

A transition between levels may be interpreted as a change in the effective properties of the medium in which interactions propagate.

This includes:

- a change in energy density,
- a change in the geometry of wave-process distribution,
- and a change in the conditions of resonant coherence.

As a result, the quantity c_n, which determines the limiting interaction speed, also changes.

Absence of universal comparison of speeds

An important consequence follows from the above considerations: comparing speeds associated with different levels of description within a single common scale is not meaningful.

In other words, the quantities c_n and c_{n+1}:

- are not required to coincide,
- and are not required to obey a single universal constraint.

This is because they correspond to different interaction regimes, each defined by its own set of parameters.

8.5 Preparation for the Analysis of Limiting Regimes

The results obtained allow us to draw the following conclusion.

The limiting speed of interaction propagation:

- is a fundamental characteristic within a fixed level;
- but does not possess a universal character when considering the full hierarchy of levels.

This implies that situations are possible in which processes associated with different levels, when compared, may exhibit effective speeds exceeding the value of ccc observed at a given level.

At the same time, such effects do not require a violation of the internal consistency of physics at each level, but arise as a consequence of differences in the regimes of description.

This issue requires a more detailed analysis, which will be presented in the following subsection.

8.6 Possibility of Regimes Formally Exceeding the Speed of Light

In the previous sections, it was shown that the limiting speed of interaction propagation c_n is a characteristic of a specific scale level and is determined by the coherence conditions of wave processes in the medium.

It follows that the value c_n, observed within a given level, is not required to remain unchanged when transitioning to other levels of description.

Constraint within a level and its interpretation

Within a fixed level, the limiting speed c_n:

- defines the maximum speed of interaction transfer;
- sets the boundary of causally connected description;
- ensures the coherence of wave structures.

Violation of this constraint within a single level leads to the breakdown of stable configurations and therefore does not occur in observable physical processes.

Thus, within one level, the quantity c_n indeed acts as a fundamental limit.

Comparison of different levels

A different situation arises when considering processes belonging to different scale levels. Let there be two levels of description, ***n*** and ***n+1***, for which:

$$c_{n+1} \neq c_n$$

Then, the velocity expressed in the units of level ***n*** for a process occurring at level ***n+1*** may be written as:

$$v_{\text{eff}} = \frac{c_{n+1}}{c_n} c_n = c_{n+1}$$

If $c_{n+1} > c_n$, then from the perspective of an observer at level nnn, such a velocity would appear to exceed the limiting value c_n.

It is important to emphasize that:

- at level ***n+1***, this value is not superliminal;
- it corresponds to its own limit c_{n+1};
- and it does not lead to a violation of internal consistency of processes.

Physical meaning of the observed excess

Thus, a formal excess of the speed of light arises not as a result of accelerating an object within a given level, but as a consequence of comparing processes belonging to different levels of description.

This distinction is fundamental.

In the first case (acceleration within a level), exceeding c_n is impossible, as it violates coherence conditions.

In the second case (inter-level comparison), one is comparing quantities that belong to different interaction regimes, which does not require adherence to the same limiting constraint.

Connection with the informational description

From the standpoint of information transfer, this implies the following.

Within a single level:

- information propagates no faster than c_n;
- causal structure is preserved;
- standard physical constraints are satisfied.

However, when considering processes associated with different levels:

- the observed "velocity" may exceed c_n;
- while information transfer within each level remains limited;
- and causality is not violated, since it is defined by the interaction structure at the corresponding level.

Interpretation within the model

Within the proposed framework, this means that:

- the speed of light is not a universal limit for all possible processes;
- it defines a boundary only for a fixed scale level;
- and observed deviations from this limit may indicate the involvement of other dynamical levels.

Thus, the existence of regimes is allowed which, when interpreted within a single level of description, appear superluminal, but in reality correspond to the normal dynamics of another level.

8.7 Interpretation of Inter-Level Effects in Terms of Observation and Resonance

In the previous section, it was shown that a formal excess of the speed of light may arise when comparing processes belonging to different scale levels.

For a correct interpretation of such effects, it is necessary to clarify how observation and interaction between levels are realized.

Limited nature of observation

As noted earlier, the observed physical picture is determined not only by the internal dynamics of a system, but also by the nature of the interaction through which observation is performed.

Within a fixed level:

- only a portion of the total information about the system is accessible;
- only those parameters that can be transmitted through available interactions are observed;
- the internal structure of deeper levels may be inaccessible to direct measurement.

This leads to the fact that processes belonging to different levels may have different representations in the observed picture.

Resonance as a mechanism of inter-level coupling

Since interactions in the model are interpreted as a result of resonant coherence, the connection between levels must also be of a resonant nature.

This implies that:

- interaction is possible only under matching of frequency characteristics;
- direct exchange between arbitrary levels is difficult or impossible;
- observable effects arise under conditions of partial coherence.

In this sense, inter-level interaction is not universal, but is determined by resonance conditions.

Effective manifestation of inter-level processes

If a process occurring at level ***n+1*** interacts with a system at level ***n***, the observed picture may include:

- distortions of temporal characteristics,
- changes in the perceived speed of processes,
- the appearance of correlations that do not fit within a local description.

Such effects may be interpreted as:

- "accelerated" processes,
- and, in the limiting case, as formally superluminal.

It is important to emphasize that these manifestations are not a direct transfer of dynamics between levels, but rather a projection onto the limited space of observation.

Projection and loss of information

In accordance with the approach outlined in the work on the emergence of dimensions, observation may be regarded as a projection of a more complex process onto a limited number of coordinates.

Under such a projection:

- part of the information is lost,
- different states may become indistinguishable,
- and effective simplified laws emerge.

In particular, a process with a higher "coherence speed" at another level may, under projection, appear instantaneous or superluminal.

However, this is a consequence of reduction in description, not a violation of fundamental constraints.

Connection with the concept of causality

Within the framework of the model, causality is defined by the structure of interactions within a given level.

Since within each level the limitation on the speed of information transfer is preserved, causal structure is not violated.

Observed "anomalous" effects arise from the comparison of different levels and do not lead to contradictions if the distinction between regimes of description is properly taken into account.

8.8 Fractal Scaling of Energy and Fundamental Physical Parameters

Within the framework of the proposed model, the observable picture of the Universe arises due to the phenomenon of resonance. This phenomenon is closely related to the concept of energy and the rate of its transfer and propagation. The latter parameter varies depending on the value of the base frequency under consideration, which is in resonance with the overall system. At the same time, the concept of energy within such a system remains an invariant means of interaction between levels. It characterizes the system's capacity to produce changes, acting as a form of stored potential to perform work.

All of this collectively ensures the validity of the law of conservation of energy. At the same time, the rate of interaction, i.e., the rate of energy transfer, changes depending on the variation of the resonant frequency. Frequency itself, in the simplest case, may vary linearly. Given that in this model the notion of a physical medium is absent, and its only defining property is the condition of resonance—ensuring lossless energy transfer—it is reasonable to assume that the rate of energy transfer must change according to the same principle as frequency, i.e., linearly in the simplest case. Thus, a change in frequency by a factor of $\boldsymbol{n}$ should lead to a proportional change in the rate of energy exchange by the same factor.

At the same time, the concept of phase must be taken into account. The phases of oscillations determine the regimes of energy exchange. It is precisely the phase that governs the discrete transfer of energy between dimensions. Returning to the construction of the mathematical model, it is the phase that determines the number of observable stable particles of baryonic matter and antimatter in the Universe we observe.

All subsequent considerations will focus on objects of baryonic matter (stable elementary particles), since they represent a "frozen" manifestation of resonance in the observable Universe and define a specific fractal level associated with the base frequency. These results may later be extended to macroscopic objects, though with certain limitations.

It is also necessary to introduce an important clarification, already discussed in the work *"Emergence of Dimensions and the Perception of Fractality."* The perception of fractality should be considered from two perspectives:

- for a fixed base frequency, structural similarity can only be perceived as a single-step transition within a given dimension: from larger to smaller scales or vice versa. In this sense, two representative structures may be identified: an elementary particle and, tentatively, a galaxy (with certain reservations);
- when the process is considered independently of a specific base frequency, it becomes possible to observe the emergence of similar "pictures" of the Universe under changes in the base frequency, each associated with its own interpretation of physical quantities.

Thus, under a fixed local reference, fractality in the general sense is distorted and can only manifest as a single step. Moreover, the formation mechanisms of elementary structures will differ.

However, the resulting structures will exhibit similar properties, such as the concept of size and regions of informational inaccessibility.

Detaching from a specific reference allows one to observe the recurrence of similar structures associated with different base frequencies. This approach enables the establishment of analogies between levels under changes in base frequency. However, it does not provide a direct translation of physical quantities as perceived within a given base level. In other words, it serves to construct analogies, but not to describe the physical perception of reality itself.

Let us proceed without introducing new assumptions and rely on well-established results. Consider the equation:

$$E = mc^2$$

We use this expression as an invariant representation of energy. Energy is assumed to act as an invariant across all levels. At the same time, the remaining physical quantities, according to the principles underlying this model, are allowed to vary.

The expression can be rewritten as:

$$E = (mk^2)\left(\frac{c}{k}\right)^2 = MC^2$$

where:

- ***M*** is the effective mass of an elementary particle at another level;
- ***C*** is the effective speed of interaction (analogous to the speed of light) at that level.

The coefficient ***k*** may also be replaced by its reciprocal ***1/k***.

This transformation is mathematically consistent and allows the introduction of a mechanism for changing two physical quantities: mass and interaction speed, which forms the basis of this model.

The energy of elementary objects at any level ***n*** can be expressed through the mass M_n of the object and the characteristic interaction speed C_n of that level.

In Section 7.1.2 it was shown that there exist natural bounds for sizes ($1/c^2 \lesssim L \lesssim 1/c$) and masses ($2\pi/c^4 \lesssim M \lesssim 2\pi/c^3$) of stable standing waves at the observed level. Beyond these bounds, the interaction speed ccc is no longer capable of sustaining wave processes with the same parameters, leading to a discrete transition to another fractal level, accompanied by a discontinuous change in physical quantities.

The quantity $2\pi/c^4$, which characterizes the minimal possible increment of mass for a standing wave, plays a key role in this transition. It defines the basis for quantization and scaling within the chosen level.

It has also been shown that the value $2\pi/c^4$ is very close to the Planck constant. Moreover, its role as a quantization coefficient suggests that they may represent the same underlying entity.

At present, the model does not provide a precise explanation for the numerical discrepancy between them. Various reasons may account for this, which are beyond the scope of this work. In general, theoretical and experimental values may differ due to the idealized nature of the model, which cannot fully capture the dynamics of reality. To avoid introducing additional constants, we define the theoretical Planck constant h_{theor} and the corresponding reduced constant $\hbar_{theor}$.

The existence of a minimal mass suggests that mass is formed in discrete portions following a linear law. Accordingly, the coefficient $\boldsymbol{k}$ should be related to h_{theor}.

At this point, an important distinction must be made:

Principle of separation between geometry and physics. The theoretical Planck constant in the model is given by: $h_{theor}=2\pi/c^4$. This expression can be separated into two components:

- $\boldsymbol{2\pi}$ — a dimensionless factor reflecting universal circular/spherical geometry;
- **$1/c^4$** — a quantity determined solely by the fundamental constant $\boldsymbol{c}$.

Choice of scaling quantum: It is reasonable to assume that the quantum governing transitions between fractal levels should be determined by the physics of the system (through $\boldsymbol{c}$), rather than by universal geometry. Therefore, it is more appropriate to use the reduced Planck constant without the geometric factor 2π. Let us denote its theoretical analogue as $\hbar_{quant}$:

$$\hbar_{\text{quant}} = \frac{\mathrm{h}_{\text{theor}}}{2\pi} = \frac{1}{c^4}$$

Using $\hbar_{quant}$, we can express the scaling laws:

Relative mass at a neighboring level:

$$M = \mathrm{m} \cdot (\hbar_{\text{quant}})^2 = \mathrm{m} \cdot (1/\mathrm{c}^4)^2$$

Relative interaction speed:

$$C = \frac{c}{\hbar_{\text{quant}}} = c \cdot (\mathrm{c}^4)$$

Alternative representation:

$$M = \frac{\mathrm{m}}{\hbar_{\text{quant}}^2} = \mathrm{m} \cdot (\mathrm{c}^4)^2$$

$$C = c \cdot \hbar_{\text{quant}} = c \cdot (1/\mathrm{c}^4)$$

In the general case, these relations can be combined into:

$$\mathrm{M}_n = \mathrm{m} \cdot \left(\hbar_{\text{quant}}\right)^{2\mathrm{n}}$$

$$C_n = \frac{c}{\hbar_{\text{quant}}^n}$$

where n=−1, 0, 1.

Here, n=1 corresponds to decreasing mass manifestation and increasing interaction speed, while n=−1 corresponds to increasing mass manifestation and decreasing interaction speed.

8.9 Scaling Law for Size

In Section 7.1.2, we obtained the maximum size limit of standing waves at a given interaction speed ccc:

$$L_{max} = c\Delta t = c\frac{1}{c^2} = \frac{1}{c}$$

Accordingly:

- At the base level (n=0): $L_0=1/c$:
- At level n: $L_n=1/C_n$

On the other hand, since: $C_n=c/(\hbar_{quant})^n$

we obtain:

$$\frac{L_n}{L_0} = \frac{c}{C_n} = \frac{c}{c}\hbar_{\text{quant}}^n = \hbar_{\text{quant}}^n$$

which gives:

$$L_n = L_0\hbar_{\text{quant}}^n$$

Thus, for the size we obtain:

$$R_{\text{n}} = R_0 \cdot \hbar_{\text{quant}}^n$$

In all formulas, ***n*** can take the values −1, 0, and 1.

8.10 Scaling Law for Frequency and the Nature of Inter-Scale Resonance

Having established the scaling laws for size R_n and the energy exchange speed C_n, we can determine how the frequency ν_n scales across different levels so that the wave relation $\lambda_n\nu_n=C_n$ (where $R_n\propto\lambda_n$) holds at all levels.

From $\nu_n\propto C_n/R_n$ and the established scaling laws:

- $C_n\propto(\hbar_{\text{квант}})^{-n}$
- $R_n\propto(\hbar_{\text{квант}})^{n}$

we obtain:

$$\nu_{\text{n}} \propto \frac{\hbar_{\text{quant}}^{-n}}{\hbar_{\text{quant}}^{n}} = \hbar_{\text{quant}}^{-2n}$$

Thus, we arrive at the fundamental scaling law for frequency:

$$\nu_n \propto \nu_0 \cdot \hbar_{\text{quant}}^{-2n}$$

This implies that frequency is not invariant, but varies with the fractal level even more significantly than other parameters. When transitioning to the macroscopic level (n=–1), the frequency decreases dramatically. However, this behavior is already embedded in the foundations of the model: frequency serves as the basis for the emergence of dimensions, and its variation follows a quadratic law.

At the same time, the fundamental principle of resonance is not violated, but rather refined. Resonance between fractal levels occurs not because their frequencies are identical, but because they are harmonically related (coherent). This mathematical relationship is the mechanism that ensures self-similarity and interaction between the micro- and macroscopic worlds.

8.11 Fractal Structure and Generalization of the Scaling Model of Interactions

The relations considered in the previous sections allow us to formulate a generalized representation of the structure of physical processes within the proposed model.

Hierarchy of scale levels

The model is based on the assumption of a hierarchy of scale levels, each corresponding to a specific regime of wave dynamics.

At each level:

- stable structures are formed (interpreted as particles or macroscopic objects);
- specific conditions of resonant coherence are realized;
- and a characteristic limitation on the speed of interaction transfer applies.

Thus, the observed physical picture represents not a single universal system with fixed parameters, but a set of interconnected levels of description.

Role of the limiting speed

Within this framework, the limiting speed of interaction propagation:

- is a fundamental characteristic within a specific level;
- is determined by the coherence conditions of wave processes;
- and remains invariant in the description of local phenomena.

However, when considering the full hierarchy of levels:

- this quantity ceases to be a universal constant;
- and should be regarded as a parameter dependent on the scale level.

This implies that the speed of light ccc, as observed experimentally, is a particular case of a more general principle applicable to a specific level of matter organization.

Inter-level effects

Transitions between levels are accompanied by changes in:

- characteristic process frequencies,
- medium parameters,
- and interaction conditions.

As a result:

- the limiting speed changes;
- the observed dynamics acquires scale dependence;
- and effects may arise which, when interpreted within a single level, appear as deviations from standard constraints.

Such effects include, in particular, the formal exceeding of the speed of light when comparing processes belonging to different levels.

Connection with the wave nature of matter

The obtained results are consistent with the initial assumption of the wave nature of matter.

If physical objects are regarded as stable configurations of wave processes, then:

- their properties are determined by resonance conditions;
- their interaction is governed by coherence mechanisms;
- and observable parameters correspond to characteristics of the relevant level of description.

In this case, fractal structure emerges as a natural consequence of the scalability of wave dynamics.

Final generalization

Within the proposed model:

- physical reality is described as a hierarchy of interconnected wave levels;
- each level possesses its own parameters, including a limiting interaction speed;
- the observed invariance of physical laws pertains to a fixed level of description;
- inter-level transitions lead to changes in parameters and the possible emergence of effects not captured by a local description;
- while the internal consistency of physical processes at each level is preserved.

Thus, the proposed model allows the interpretation of the limitations observed in physics not as absolute, but as scale-dependent, while preserving their fundamental role within the corresponding level.

9. Consistency of Theoretical Calculations with Observed Quantities

In the previous sections, a model was proposed in which physical objects are treated as stable wave configurations, and their properties as parameters of the corresponding level of description.

A key element of this model is the assumption of a fractal hierarchy of scales, as well as the idea that observable physical quantities arise as manifestations of a unified wave process, described in terms of frequency and scaling characteristics.

Unlike the initial stage of the model's development, where these assumptions were considered as hypotheses, in the present work they are employed as a methodological foundation, based on the results presented in the work *"The Emergence of Dimensions and the Perception of Fractality."*

9.1 Principle of Comparison

The comparison of theoretical results with observed quantities within this model has several distinctive features.

First, physical quantities are treated as parameters of the level of description rather than as absolute characteristics. This implies that their values may depend on the chosen scale and the conditions of observation.

Second, the use of a dimensionless representation leads to a comparison with experimental data not through direct numerical agreement of dimensional quantities, but through:

- order of magnitude,
- relationships between parameters,
- and structural dependencies.

Thus, the purpose of comparison is not to obtain exact numerical values, but to test the consistency of the model with observed regularities.

9.2 Masses of Elementary Particles

In Section 7, it was shown that the masses of elementary particles can be related to the amplitude characteristics of standing wave configurations.

The obtained estimates:

- reproduce the correct order of magnitude,
- demonstrate power-law dependencies of parameters,
- and allow the differences in masses to be interpreted in terms of the geometry of the wave structure.

Discrepancies with experimental values may be attributed to:

- the simplified nature of the model,
- the presence of internal dynamics,
- and limitations of the applied approximation.

Thus, the model provides not an exact calculation of masses, but a physical interpretation of them.

9.3 Speed of Light and the Limitation of Interactions

Within the model, the speed of light is interpreted as the limiting speed of coherence of wave processes at a given level.

This is consistent with experimental observations, in which:

- the speed of light represents the maximum speed of interaction transfer,
- and serves as a fundamental characteristic of the observed level.

At the same time, the model allows for this limitation to be scale-dependent, which does not contradict observational data, since all measurements are performed within a single level of description.

9.4 Planck Constant and Quantization

The estimates obtained in Section 7 lead to expressions of the form:

$$\frac{2\pi}{c^4}$$

which are close in order of magnitude to the Planck constant.

Within the framework of the model, this is interpreted as follows:

- the Planck constant is not an independent fundamental quantity;
- it reflects the structure of the wave process and the conditions of quantization;
- its value is determined by the properties of the medium and the geometry of wave configurations.

Possible discrepancies between theoretical and experimental values may be attributed to the characteristics of real physical systems and to measurement processes.

9.5 Scale Correspondence

One of the most significant implications of the model is the possibility of comparing objects across different scales.

In particular:

- the parameters of elementary particles,

- when appropriately scaled,
- may be related to the parameters of astrophysical objects.

This result should not be interpreted as a direct identity between such objects, but rather as an indication of structural similarity arising from fractal organization.

Such correspondences require further verification and may be considered a direction for future research.

9.6 Frequency as a Fundamental Characteristic

One of the key outcomes of the model's development is the conclusion that frequency may be regarded as a more fundamental characteristic than traditional physical quantities.

In this context:

- mass, energy, and spatial scale appear as derived parameters;
- frequency determines the dynamics and resonance conditions;
- and the observed physical picture arises as a result of interpreting these processes within a given level of description.

This statement is directly connected with the approach outlined in the work on the emergence of dimensions and represents its extension within the framework of the physical model.

9.7 Concept of Frequency Levels and Possible Multiplicity of Regimes

Within the proposed model, space is not treated as a medium analogous to the ether that determines the speed of interaction propagation. The limiting speed at each level is defined by the conditions of resonant coherence of wave processes.

Thus, frequency emerges as the fundamental characteristic.

From this perspective, two aspects of level multiplicity can be distinguished.

Fractal hierarchy

The observed world, characterized by a base speed $\boldsymbol{c}$ and frequency ν_0, represents a fractal structure containing a sequence of levels:

$$\nu_n = \nu_0 \cdot (\hbar_{\text{квант}})^{-2n}, n \in Z$$

Each level possesses its own characteristic frequency and is related to others through scaling transformations.

Possibility of independent regimes

The model allows for the existence of other systems based on different fundamental parameters:

$$(c', \nu_0'), (c'', \nu_0''), \ldots$$

It is assumed within this framework that energy exchange between such systems is not observed, since resonance is the only mechanism of interaction. In the absence of frequency matching, interaction does not occur.

This leads to a rejection of the concept of a medium in the classical sense: interaction is determined not by the presence of a "filling medium," but by conditions of resonant coherence.

9.8 Resonance as a Mechanism Limiting Observability

Within the model, interaction is determined by conditions of resonant coherence, which leads to a fundamental limitation of observability.

Only those processes that are in resonance with a given level, and whose speed does not exceed the limiting interaction speed of that level, are observable.

If a process occurs at higher speeds, then, even in the presence of resonant coupling, an observer may register the fact of change but is unable to unambiguously determine its cause. In this case, part of the information about the process becomes inaccessible, making complete description and exact calculation impossible.

In this sense, the phenomenon of uncertainty, as considered in quantum mechanics, may be interpreted as a consequence of the limitations of resonant interaction and observation.

This implies that:

- observation is limited by the frequency range of the corresponding level;
- objects and processes manifest only under conditions of resonant coupling;
- the perceived physical picture is the result of selecting accessible interactions.

As a consequence:

- observed reality represents a partial slice of a more general structure;
- processes may exist that are not detectable within the current level;
- the limiting speed ccc applies only to the given resonant regime.

9.9 Horizons of Knowledge

The proposed model points to the limited nature of the observed picture of the world.

It suggests that:

- reality may be significantly more complex than its observable manifestation;
- the accessible level of knowledge is determined by the parameters of the current scale level;
- the expansion of understanding is associated with going beyond the limits of the existing description.

At the same time, the model is not final and requires further development.

9.10 Limitations and Domain of Applicability

It should be emphasized that the proposed model:

- is theoretical in nature;
- employs simplified representations of wave structures;
- and does not claim to provide an exact quantitative description of all physical processes.

Its primary goal is to offer a unified interpretative framework that connects:

- microscopic and macroscopic levels,
- the wave nature of matter,
- and observed physical laws.

9.11 Comparison with Experimental Data

To test the hypothesis, calculations of key parameters of elementary particles (neutrino, electron, neutron, proton) based on the wave model have been performed. The results were compared with experimentally measured values:

n	name	λ_0 (m)	M_0 (кг)	m_0 (kg)	d_0 (m)	λ_0 exp (m)	m_0 exp (kg)	d_0 exp (m)
1	neutrino	$9{,}715\times10^{-11}$	$2{,}663\times10^{-32}$	$6{,}581\times10^{-37}$	$9{,}715\times10^{-11}$	10^{-6}	$<2.2\times10^{-37}$	10^{-10}
2	electron	$2{,}83\times10^{-12}$	$9{,}149\times10^{-31}$	$9{,}149\times10^{-31}$	$4{,}244\times10^{-12}$	2.43×10^{-12}	9.109×10^{-31}	10^{-18}
3	neutron	$8{,}241\times10^{-14}$	$3{,}142\times10^{-29}$	$1{,}617\times10^{-27}$	$1{,}648\times10^{-13}$	10^{-15}	1.675×10^{-27}	10^{-15}
4	proton	$2{,}4\times10^{-15}$	$1{,}078\times10^{-27}$	$1{,}617\times10^{-27}$	$6{,}001\times10^{-15}$	1.32×10^{-15}	1.673×10^{-27}	10^{-15}

Notes:

- λ_0 is the characteristic wavelength from the model;
- M_0 is the amplitude of the wave;
- m_0 - resultant mass, depends on the amplitude of the wave and the number of half-waves associated with the centre point of the wave structure;
- d_0 is the calculated diameter (or radius) of the wave structure;
- "exp" - experimental values.

Elementary charge obtained in the model:

$\mathbf{q_0 = 1.5506912... \times 10^{-19}}$ **C**,

which is comparable with the experimental value

$\mathbf{e = 1.602176634 \times 10^{-19}}$ **C** — the error is less than 3.2%.

The obtained values of mass, wavelength, and radius agree well with the experimental ones, especially for the electron and proton. This confirms that standing waves in the medium can be the basis for the formation of stable particles and their properties.

The obtained value of the elementary charge is also close to the experimental one, which indicates the possibility of describing the electromagnetic interaction through the internal structure of the wave object.

10. Logical Consequences of the Model

Based on the proposed model, in which physical reality is described as a system of interconnected wave processes organized according to the principles of resonance and fractal scalability, a number of logical consequences can be formulated.

These consequences do not represent isolated assumptions but rather natural outcomes of the adopted interpretation, which links the structure of matter, interactions, and the observed physical picture.

10.1 Consequences Concerning the Nature of Matter

Wave Structure of Matter

Matter is considered as a set of stable wave configurations. The spatial characteristics of objects (sizes, boundaries, distances) are directly determined by the parameters of these configurations and are not externally imposed. Geometry thus appears as a manifestation of the internal structure of the wave process.

Nature of Mass

Mass is interpreted as a characteristic of a stable wave state. It is associated with the parameters of the configuration—amplitude, frequency, and structural complexity. Thus, mass is not an intrinsic property but arises as a consequence of the formation of a stable resonant regime.

Origin of Electric Charge

Electric charge is treated as a characteristic of a specific class of wave configurations, determined by their geometry and formation conditions. Its quantization and stability are explained by the fact that such states are realized only under specific resonant conditions common to a given level of description.

10.2 Consequences Concerning Interactions

Resonance as a Universal Mechanism of Interaction

All fundamental interactions are interpreted as different manifestations of a unified process of resonant energy exchange between wave structures. Differences between interaction types are determined by the parameters of the configurations and the conditions of their coherence.

Nature of Gravitation

Gravitation is considered as a consequence of changes in the energy distribution within a system of wave processes. It arises as a response to the formation of stable configurations and manifests as a tendency toward redistribution of energy density and coherence of states.

10.3 Consequences Concerning the Organization of Reality

Fractal Structure of Levels

Physical reality exhibits a hierarchical organization in which different scale levels are connected through the laws of wave dynamics. Parameters such as mass, size, frequency, and the limiting interaction speed change across levels, while their relationships remain preserved.

Invariance of the Energy Relation

Despite scale transformations, the energy relation retains its form. This reflects the internal consistency of the model and indicates that energy serves as a universal characteristic of state, independent of a particular level of description.

Frequency as a Fundamental Parameter

Frequency acts as the fundamental quantity determining the structure and dynamics of the system. Mass, spatial scale, and other physical quantities are derived from frequency relations and resonance conditions.

Limited Nature of the Observed Picture

The observed physical reality is determined by conditions of resonant interaction. This implies that the perceived picture represents only a partial projection of a more general underlying dynamics, and processes not in resonant relation with a given level may not manifest in observation.

10.4 Consequences Concerning Dynamical Processes

Absorption and Emission of Energy

Processes of emission and absorption are interpreted as transitions between different resonant states. They are not associated with the creation or annihilation of matter, but rather reflect a reconfiguration of the wave structure within the overall dynamics.

Structural Change Under Interaction

Any interaction leads to a change in the configuration of wave structures. This may manifest as variations in frequency, amplitude, or spatial organization, which at the macroscopic level are perceived as changes in the physical properties of the system.

Relation Between Dynamics and Observation

Since observation is determined by resonant conditions, not all processes can be fully detected or described. This leads to limitations in precise prediction and may manifest as uncertainty in the description of dynamical processes.

10.5 Dependence of the Interpretation of Physical Parameters on the Level of Perception

Within the proposed model, physical reality is described as a system of interconnected frequency levels formed according to a specific scaling law. At the same time, these frequency relations may be defined relative to different base values.

This implies that the same system of frequency levels can be interpreted in different ways depending on the chosen base frequency used to construct the hierarchy.

As a result:

- identical frequency values may correspond to different physical parameters (such as space, mass, or interaction) depending on the level of description;
- different descriptive systems may partially overlap in frequency values while remaining independent in terms of observation;
- the observed physical picture is determined not only by the structure of the system but also by the mode of its interpretation.

This leads to the following consequence: the laws describing relationships between parameters remain invariant, while their physical interpretation depends on the level of perception.

In this sense, different "modes of description" of the same structure are possible, which:

- obey the same underlying laws,
- but do not coincide in their observable physical manifestations.

In this context, the level of perception may be associated with the observational system that determines how frequency relations are interpreted. In particular, for an observer possessing consciousness, the structure of perception defines the base level relative to which the physical picture is formed.

This implies that the same frequency structure may correspond to different interpretations depending on the parameters of the perceptual system. At the same time, the underlying interaction laws remain unchanged, while their physical meaning is determined by the conditions of observation.

Within the framework of the proposed model, physical reality is described as a system of interconnected frequency relations, while no absolute base frequency is specified. This implies that the description of the structure depends on the choice of the reference level relative to which the interpretation is carried out.

In this context, the role of such a reference level may be associated with the system of perception that determines how frequency relations are interpreted. In particular, for an observer possessing consciousness, the structure of perception defines the base level relative to which the observed physical picture is formed.

Thus, within this model, consciousness is not treated as a derivative of matter, but rather as a factor that determines the mode of its perception and interpretation. At the same time, the underlying structure of interactions and their governing laws remain independent of the specific observer.

In this sense, the observed physical reality may be regarded as the result of a correspondence between the objective structure of the system and the conditions of its perception.

Conclusion

In this work, an attempt has been made to develop a unified conceptual and mathematical framework for describing physical reality within the framework of the *"Wave Model of Matter and the Fractal Structure of the Universe."*

The proposed approach is based on a limited set of postulates in which energy is considered the primary foundation, space is treated as an active medium of wave processes, and resonance is regarded as a universal mechanism of interaction. This made it possible to construct a model aimed at providing a physically intuitive and internally consistent explanation of the fundamental properties of matter and the observed laws of nature.

A key result of the work is the development of a mathematical framework (Chapter 7), which, based on the geometry of standing waves and the limiting speed of interactions, allows for the estimation of the main parameters of stable elementary particles. Characteristic values of masses, wavelengths, and sizes were calculated for the neutrino, electron, proton, and neutron, and an interpretation of the elementary charge was also proposed.

The analysis showed that for simple wave structures, such as the electron, the theoretical estimates demonstrate good agreement with experimental data. For more complex systems—nucleons—systematic discrepancies were identified. Within the framework of this work, an explanation is proposed: the experimental standards and fundamental constants in use are calibrated based on complex composite systems, which leads to a "structural distortion" when compared with idealized wave models. In this sense, the discrepancies may be interpreted not as a limitation of the model, but as its predictive consequence.

An important result is the application of the principle of fractal scaling (Chapter 8). It is shown that the use of theoretical wave parameters of elementary particles, together with the introduced scaling quantum, leads to estimates of macroscopic structures that agree in order of magnitude with the observed characteristics of galactic systems. This indicates the possibility of a unified description of microscopic and cosmological levels within the proposed model.

The issue of mass consistency under scaling remains open. The observed discrepancies may be related to the indirect nature of mass determination both at the microscopic and astrophysical levels, as well as to the fact that existing models do not fully account for the complex internal dynamics of structures.

An additional factor is the evolution of experimental knowledge: known parameters of the micro-world and cosmological objects may undergo significant revision as measurement methods improve. This requires caution in interpreting discrepancies and does not allow them to be unambiguously regarded as a refutation of the model.

Within the proposed approach, the complex rotational structure of macroscopic objects may lead to effects that differ from the predictions of simplified models, which may be related to the interpretation of phenomena attributed to dark matter.

Thus, the proposed model represents an internally consistent system that:

- allows the estimation of elementary particle parameters from unified principles;
- offers an interpretation of discrepancies with experiment through the specifics of measurement standards and structural properties of objects;
- demonstrates scale consistency in the transition from micro- to macro-levels;
- provides a qualitative explanation for a wide range of phenomena within a unified framework.

The work does not claim completeness and requires further development. Its primary goal is to establish a unified interpretative approach linking different levels of matter organization through the principles of wave dynamics, resonance, and fractality.

The proposed model is not intended to refute existing physical theories, but may be considered as an attempt to unify them and provide a deeper physical interpretation. It suggests viewing the fundamental properties of matter and the laws of nature as consequences of a universal energy dynamics manifesting across different scales.

An important consequence of the proposed approach is the distinction between the objective structure of the system and its observable representation. It is shown that, in the absence of a fixed base frequency, the interpretation of physical parameters inevitably depends on the chosen level of description. In this context, the observed physical reality may be regarded as the result of a correspondence between the structure of the system and the conditions of its perception. This points to the fundamental role of the observational system in shaping the physical picture, while preserving the invariance of the underlying interaction laws.

Related Works and Author's Publications

This work is part of a series of publications in which the proposed approach is progressively developed and refined.

1. *Reflections: Belief, Disbelief. Spirit and Matter*
   https://zenodo.org/records/19260065
   — a philosophical and ethical work outlining the initial ideas and the broader conceptual framework.
2. *Energy as Fundamental Reality: From Points to Processes*
   https://zenodo.org/records/17170686
   — formulation of the ontological foundation, where physical reality is considered as a set of processes rather than static objects.
3. *Wave Equilibrium Hypothesis: The Universe as a Balanced State of Zero*
   https://zenodo.org/records/19307384
   — exploration of a possible mechanism for the emergence of physical reality.
4. *Emergence of Dimensions as a Result of Fractal Resonance*
   https://zenodo.org/records/19688973
   — description of the mechanism underlying the formation of dimensional structure and scaling levels.
5. *Consciousness as a Wave Structure: A Possible Link Between Brain Frequencies and Perception Frequencies*
   https://zenodo.org/records/19332683
   — investigation of the potential role of consciousness within the proposed framework.
6. *Unity of the Wave: Matter, Energy, and Consciousness as Aspects of Frequency*
   https://zenodo.org/records/17432603
   — synthesis of key ideas and an attempt to unify different aspects of the model.
7. *A Simple Picture of Gravity Through Fields and Gradients*
   https://zenodo.org/records/19484244
   — interpretation of gravitational phenomena within the wave-based approach.

The present work builds upon the results presented in these publications and develops them within a unified interpretative framework.

Appendices

Appendix 1. Longitudinal waves of energy in the mechanism of electromagnetic wave propagation

Introduction

In classical electrodynamics, electromagnetic waves are described as transverse and not requiring a material medium for propagation. At the same time, their propagation occurs with a finite speed, which implies a finite rate of change in the energy state of space.

Within the framework of the proposed model, space is treated as an energetically structured system in which wave propagation is accompanied by changes in energy density. This makes it possible to consider not only the transverse component of the wave process, but also a possible redistribution of energy along the direction of propagation.

Such an approach does not contradict the classical description but rather complements it by introducing consideration of a longitudinal component associated with the gradient of energy density.

A1.1 Energy Gradient and Its Consequences

During the propagation of an electromagnetic wave, energy is redistributed in space. In the vicinity of the source, the energy density gradually returns to its initial value, whereas at a distance it remains altered.

This leads to the emergence of a spatial gradient of energy density between different regions. The presence of such a gradient implies a process of its relaxation, which may be interpreted as a longitudinal component of energy redistribution.

Thus, the transverse propagation of an electromagnetic wave is accompanied by changes in the energetic state of the medium along the direction of propagation. This component may be small compared to the transverse one, which makes its direct experimental detection difficult.

A1.2 Relation to the Wave Nature of Particles

Within the wave-based interpretation of matter, stable structures are treated as standing waves. This raises the question of the mechanism responsible for their formation and stabilization.

If the propagation of wave processes is accompanied by longitudinal energy redistribution, such a component may play a role in the formation of stable configurations. In this case, a standing wave can be viewed not only as an abstract solution of equations, but also as a result of the coherence between transverse and longitudinal processes within the energetic structure of space.

This approach allows elementary particles to be interpreted as stable wave formations arising from the combined interaction of different components of the wave process.

A1.3 Conclusion

Considering the propagation of electromagnetic waves in terms of changes in energy density makes it possible to introduce an additional component associated with longitudinal energy redistribution.

This extends the interpretation of wave processes without contradicting their classical description and opens the possibility for a more comprehensive understanding of the mechanisms underlying the propagation of interactions and the formation of stable structures.

Such an approach may be useful for further analysis of the nature of wave processes and their role in the formation of physical objects across different scales.

Appendix 2. Rethinking the Michelson-Morley Experience

Introduction

The Michelson–Morley experiment (1887) is traditionally regarded as one of the key arguments against the existence of the ether—a hypothetical medium through which light propagates. The negative result of the experiment became one of the foundations for the development of special relativity, in which the speed of light is considered invariant and independent of the motion of the source or the observer.

At the same time, this result may be interpreted not only as a rejection of the existence of a medium, but also as an indication of the specific properties of its structure and observability. Within the framework of the proposed model, where matter and interactions are interpreted as wave processes in the energetic structure of space, an alternative interpretation of this experiment becomes possible.

A2.1 Experimental Setup and Result

The purpose of the Michelson–Morley experiment was to detect the so-called “ether wind,” i.e., the presumed motion of the medium relative to the Earth.

The core idea of the experiment was as follows:

- if the Earth moves through a medium, the speed of light along the direction of motion and perpendicular to it should differ;
- this difference should result in a shift of the interference pattern.

To test this, an interferometer was used to compare the propagation times of light beams in different directions.

The experiment detected only very small deviations, significantly smaller than expected, which did not allow for the observation of an effect associated with the Earth's motion relative to a hypothetical medium.

A2.2 Interpretation within the Wave Model

Within the proposed approach, matter, radiation, and measuring instruments are treated as forms of wave processes within a unified energetic structure.

If all physical objects, including the observer and measurement devices, are wave configurations, then they are governed by the same laws of propagation and interaction.

This leads to an important consequence: within such a system, it is impossible to identify an external medium or to detect its absolute motion, since there is no independent reference frame.

Even if some global dynamics of the structure exist, an observer, being part of it, cannot detect this motion, because all measurement standards (length, time, and speed) are defined within the same system.

A2.3 Relation to the Wave Nature of Matter

Modern physics recognizes the wave properties of matter. Within the proposed model, this concept is extended: elementary particles are treated as stable wave configurations formed through resonant processes.

If matter is understood as a set of such configurations, then the concept of motion of a "medium" loses its classical meaning. The medium is not external to the observer—it coincides with the very system in which observation takes place.

In this context, the inability to detect an "ether wind" may be explained not by the absence of a medium, but by the fact that observation occurs from within a unified wave structure.

A2.4 Conclusion

Within the proposed model, the result of the Michelson–Morley experiment may be interpreted as indicating the impossibility of detecting absolute motion of a medium from within the system, if matter itself and the processes of observation are forms of the wave organization of that medium.

This approach:

- does not contradict experimental data;
- preserves the invariance of the speed of light at the observable level;
- and allows for the existence of a unified structure in which wave processes take place.

Thus, the negative result of the experiment may be regarded not only as a rejection of the classical ether concept, but also as an indication of the limitations of observation in describing the global properties of the system.

Appendix 3. Standing waves of energy and structure of elementary particles

A3.1 Standing Waves of Energy Density as a Model of Elementary Particles

Within the framework of the proposed model, matter is considered as a set of stable wave configurations formed within the energetic structure of space.

A standing wave represents a stable state arising from the coherence of wave processes. Such states possess well-defined parameters (frequency, amplitude, spatial scale), which allows them to be treated as stable physical objects.

If one assumes that elementary particles correspond to such stable configurations, their fundamental properties can be interpreted as parameters of the corresponding wave states.

In this case:

- the spatial size of a particle is determined by its wavelength;
- mass is related to the stability parameters and the amplitude of the configuration;
- interaction is governed by resonant coherence between wave processes.

Thus, a particle may be considered not as a point-like object, but as a localized wave structure existing as a result of a stable resonant regime.

A3.2 de Broglie Waves as the Basis of Particle Structure

Within the hypothesis of standing waves of energy density, elementary particles may be regarded as stable configurations of such waves. In this context, the de Broglie wave associated with a particle can be considered not only as a characteristic of its motion, but also as a reflection of its internal structure.

The de Broglie wavelength is defined by the relation:

$$\lambda = \frac{h}{mv}$$

where:

- h is Planck's constant,
- m is the particle mass,
- v is the particle velocity.

If a particle is interpreted as a standing wave, then its characteristic size should be related to its wavelength, while its stability is determined by resonance conditions. In this case, allowed states may correspond to an integer number of half-wavelengths, which naturally leads to quantization of parameters.

This approach is discussed in more detail in: https://zenodo.org/records/14883086

A3.2.1 Parameter Estimation for the Proton

To assess the consistency of this interpretation, consider an estimate of the de Broglie wavelength for a proton at velocities close to the speed of light.

As $\upsilon \to c$, the relativistic momentum increases and the de Broglie wavelength decreases. To obtain a finite estimate, consider the velocity:

$$\upsilon = 0.999999999c$$

In this case:

- de Broglie wavelength:

$$\lambda \approx 1.32 \times 10^{-15}\text{m}$$

Comparing this value with the characteristic size of the proton allows estimation of the number of half-wavelengths along its diameter:

- number of half-wavelengths:

$$\text{N} \approx 2.55$$

This value is close to that expected for a stable configuration with a finite number of nodes.

A3.2.2 Interpretation of the Result

Within the framework of the model, the proton has previously been interpreted as a stable standing wave with a fixed number of nodes. In this case, the number of half-wavelengths defining its spatial structure is expected to take values close to half-integers.

The obtained value N≈2.55 is close to the expected value of approximately 2.5, which may be regarded as an indication of consistency with the wave-based interpretation.

This allows the following interpretation:

- the de Broglie wavelength may be related to the spatial structure of a standing wave;
- the wave properties of a particle may reflect not only its dynamics, but also its internal organization;
- stable states may correspond to resonant configurations with a discrete number of nodes.

A3.2.3 Conclusion

The obtained estimates do not constitute a rigorous proof, but they demonstrate a possible connection between the de Broglie wavelength and the spatial structure of elementary particles.

Within the proposed model, this allows for an interpretation in which the de Broglie wave reflects not only kinematic properties, but also structural features of particles. In this case, the corresponding wavelength may be associated with wave processes formed within the energetic structure of space.

Appendix 4: Lorentz transformation: classical derivation and wave interpretation

Introduction

Lorentz transformations are a fundamental element of relativistic physics and describe the relationship between spatial and temporal coordinates in different inertial reference frames. Their introduction is associated with the requirement of invariance of the speed of light.

Within the framework of the proposed model, in which particles are treated as wave structures, it becomes possible to interpret these transformations in terms of the geometric properties of wave processes.

A4.1 Classical Formulation

In the standard formulation, Lorentz transformations relate the coordinates in two reference frames moving relative to each other with velocity υ:

$$\mathrm{x}' = \gamma(\mathrm{x} - \upsilon \mathrm{t}), \gamma = \frac{1}{\sqrt{1 - \upsilon^2/c^2}}$$

From these relations, the length contraction effect follows:

$$\mathrm{L}' = \mathrm{L}\sqrt{1 - \upsilon^2/c^2}$$

where:

- L is the length in the rest frame,
- L' is the length in the moving frame,
- υ is the velocity,
- c is the speed of light.

A4.2 Wave Interpretation

Within the wave-based model, a particle can be treated as a localized wave structure in which the propagation of wave processes is limited by the maximum speed ccc.

If a particle moves with velocity υ, its internal dynamics must be consistent with this constraint. This allows a representation in which the total effective speed of the wave process remains equal to ccc, while its components are distributed between:

- the motion of the particle as a whole;
- the internal wave dynamics.

This leads to the relation:

$$\mathrm{c}^2 = \upsilon^2 + \upsilon_{int}^2$$

from which:

$$\upsilon_{int} = c\sqrt{1 - \upsilon^2/c^2}$$

A4.3 Consequences for Spatial Structure

If the characteristic size of a particle is determined by the parameters of its internal wave structure, then a decrease in υ_{int} leads to a change in its effective scale.

This yields:

$$\mathrm{R}' = \mathrm{R}\sqrt{1 - \upsilon^2/c^2}$$

and accordingly:

$$\mathrm{L}' = \mathrm{L}\sqrt{1 - \upsilon^2/c^2}$$

which coincides with the result obtained from Lorentz transformations.

A4.4 Interpretation of the Result

Within the proposed approach, length contraction can be interpreted as a consequence of changes in the internal structure of the wave process during motion.

Thus:

- relativistic effects may be associated with the geometry of wave processes;
- Lorentz transformations admit an interpretation in terms of the internal dynamics of particles;
- the invariance of the speed of light appears as a constraint on the total propagation speed of wave processes.

Appendix 5: Energy of a particle as a closed wave structure and the law of conservation of energy

Introduction

In modern physics, the energy of a particle in the relativistic case is given by the relation:

$$E^2 = p^2c^2 + m_0^2c^4$$

where p is the particle momentum, m_0 is its rest mass, and c is the speed of light.

This expression shows that the energy of a particle increases with its momentum. In the standard interpretation, this is associated with the kinematic effects of motion.

Within the proposed model, a particle is treated as a localized wave structure. This allows energy to be considered not only as a function of motion, but also as a characteristic of the internal organization of the wave process.

A5.1 de Broglie Wave and Structural Change

According to the de Broglie hypothesis, a particle is associated with a wavelength:

$$\lambda = \frac{h}{p}$$

where h is Planck's constant and p is the momentum.

As the velocity increases, the momentum increases and the wavelength decreases. Within the wave-based interpretation, this may be associated with a change in the spatial structure of the wave configuration.

Thus, the motion of a particle is accompanied by a change in its internal scale, reflected in the redistribution of the characteristics of the wave process.

A5.2 Particle as a Wave System

If a particle is treated as a closed wave structure, its energy may be interpreted as a characteristic of the entire configuration.

As the velocity changes, the observed energy of the particle increases, corresponding to the increase in momentum. However, within the wave interpretation, this may be associated with a redistribution of energy contributions within the structure.

In this case:

- the observed energy depends on velocity and momentum;
- the internal structure of the wave process changes with motion;
- the contribution associated with the internal configuration may decrease as the velocity increases.

Such a description does not contradict relativistic mechanics, but allows for an additional interpretation of the structure of energy.

A5.3 Derivation of the Energy Relation

Consider the relativistic expression for momentum:

$$\mathrm{p} = \frac{m_0 \upsilon}{\sqrt{1 - \upsilon^2/c^2}}$$

Substituting it into the standard energy relation, we obtain:

$$E^2 = p^2c^2 + m_0^2c^4$$

Expanding this expression in terms of velocity:

$$E^2 = \frac{m_0^2\upsilon^2}{1 - \upsilon^2/c^2}c^2 + m_0^2c^4$$

This coincides with the standard relativistic relation, but allows the energy to be represented as a sum of contributions:

- a component associated with motion (momentum);
- a component associated with internal structure (rest mass).

A5.4 Interpretation

Within the proposed approach, the energy of a particle may be considered as a quantity determined by the state of its wave configuration.

As velocity increases:

- the contribution associated with momentum increases;
- the contribution associated with internal structure changes;
- the total energy is described by an invariant relation.

In this context, relativistic effects may be interpreted as a consequence of changes in the structure of the wave process during motion.

A5.5 Limiting Case

As $\upsilon \to c$, the momentum expression tends to infinity and the de Broglie wavelength decreases.

At the same time, the contribution associated with the rest mass, expressed through the factor:

$$\mathrm{m_{eff}} = \mathrm{m_0}\sqrt{1 - \upsilon^2/c^2}$$

This is consistent with the fact that a photon has no rest mass, and its energy is entirely determined by its momentum.

A5.6 Conclusion

The obtained expression for energy coincides with the standard relativistic relation; however, within the proposed model it admits an additional interpretation.

Energy may be represented as a characteristic of a wave structure in which:

- changes in velocity lead to a redistribution of contributions;
- relativistic effects reflect changes in internal configuration;
- the invariance of the energy relation is preserved.

Thus, the motion of a particle may be interpreted as a change in the structure of the wave process, accompanied by a redistribution of energy characteristics.

Within the more general framework presented in Section 8, such redistribution may be regarded as a particular case of a scaling transformation of the wave structure, in which system parameters change while their relationships remain invariant.

Appendix 6: Calculation of particle parameters and experimental data.

We perform the calculation for all possible standing wave nodes and compare with the experimental data.

We use formulas from the chapter "7.1.3 Quantisation of knots and bounds of existence of particles":

$$M_0 = M_{min} \times k^n = \frac{2\pi}{c^4} \times \left(\sqrt[5]{\frac{c}{2\pi}}\right)^n = 2\pi c^{-4} \left(\frac{c}{2\pi}\right)^{\frac{n}{5}},$$

$$1 \leq n \leq 4$$

$$\lambda_0 = \frac{d_{min}}{k^n} = \frac{1}{c\left(\sqrt[5]{\frac{c}{2\pi}}\right)^n} = c^{-1} \left(\frac{c}{2\pi}\right)^{-\frac{n}{5}},$$

$$1 \leq n \leq 4$$

$$d_0 = \frac{n+1}{2} \lambda_0$$

A6.1 n=1 (neutrinos):

$$M_0 = 2\pi c^{-4} \left(\frac{c}{2\pi}\right)^{\frac{n}{5}} \approx 7{,}757 \times 10^{-34} \cdot 34{,}3343 \approx 2{,}663311651 \times 10^{-32},$$

$$\lambda_0 \approx \frac{1}{299792458} \cdot \frac{1}{34{,}3343} \approx 9{,}715185549090911 \times 10^{-11},$$

$$d_0 = \frac{n+1}{2} \lambda_0 \approx 9{,}715185549090911 \times 10^{-11}$$

Taking into account chapter "7.7.5 Particularities of the neutrino mass", a correction for the measured mass in the experiment has to be introduced.

$m_0 \approx 6{,}581 \times 10^{-37}$

A6.2 n=2 (electron):

$$M_0 = 2\pi c^{-4}\left(\frac{c}{2\pi}\right)^{\frac{n}{5}} \approx 7{,}757 \times 10^{-34} \cdot 34{,}3343^2 \approx 9{,}14429412189293 \times 10^{-31},$$

$$\lambda_0 \approx \frac{1}{299792458} \cdot \frac{1}{34{,}3343^2} \approx 2{,}829586025953904 \times 10^{-12},$$

$$d_0 = \frac{n+1}{2}\lambda_0 \approx 4{,}244379038930855 \times 10^{-12}$$

For the electron, the total mass is formed by only one centre half-wave, so nothing needs to be corrected.

$m_0 \approx 9{,}14429412189293 \times 10^{-31}$

A6.3 n=3 (neutron):

$$M_0 = 2\pi c^{-4}\left(\frac{c}{2\pi}\right)^{\frac{n}{5}} \approx 7{,}757 \times 10^{-34} \cdot 34{,}3343^3 \approx 3{,}139629376693084 \times 10^{-29},$$

$$\lambda_0 \approx \frac{1}{299792458} \cdot \frac{1}{34{,}3343^3} \approx 8{,}24128066089568 \times 10^{-14},$$

$$d_0 = \frac{n+1}{2}\lambda_0 \approx 1{,}648256132179135 \times 10^{-13}$$

For neutrons, mass correction is not so obvious, so we will calculate it using the formula given in section 7.7.4, ‘Calculation of neutron mass (n=3) – taking into account internal rotation.’

We increase the amplitude by a factor of 3/2, then increase it by one quantum:

$m_0 \approx 3{,}139629376693084 \times 10^{-29} \times 34{,}3343 \times 1{,}5 \approx 1{,}616954653622901 \times 10^{-27}$

A6.4 n=4 (proton):

$$M_0 = 2\pi c^{-4}\left(\frac{c}{2\pi}\right)^{\frac{n}{5}} \approx 7{,}757 \times 10^{-34} \cdot 34{,}3343^4 \approx 1{,}077969769081934 \times 10^{-27},$$

$$\lambda_0 \approx \frac{1}{299792458} \cdot \frac{1}{34{,}3343^4} \approx 2{,}400305426612944 \times 10^{-15},$$

$$d_0 = \frac{n+1}{2}\lambda_0 \approx 6{,}00076356653236 \times 10^{-15}$$

We have discussed the derivation of the proton mass in chapter "7.7.2 Transition to the mean distribution".

$m_0 \approx 1{,}077969769081934 \times 10^{-29} \times 1{,}5 \approx 1{,}616954653622901 \times 10^{-27}$

The experimental data was taken from the internet. Based on the data obtained, a table was drawn up:

n	name	λ_0 (m)	M_0 (кг)	m_0 (kg)	d_0 (m)	λ_0 exp (m)	m_0 exp (kg)	d_0 exp (m)
1	neutrino	$9{,}715\times10^{-11}$	$2{,}663\times10^{-32}$	$6{,}581\times10^{-37}$	$9{,}715\times10^{-11}$	10^{-6}	$<2.2\times10^{-37}$	10^{-10}
2	electron	$2{,}83\times10^{-12}$	$9{,}149\times10^{-31}$	$9{,}149\times10^{-31}$	$4{,}244\times10^{-12}$	2.43×10^{-12}	9.109×10^{-31}	10^{-18}
3	neutron	$8{,}241\times10^{-14}$	$3{,}142\times10^{-29}$	$1{,}617\times10^{-27}$	$1{,}648\times10^{-13}$	10^{-15}	1.675×10^{-27}	10^{-15}
4	proton	$2{,}4\times10^{-15}$	$1{,}078\times10^{-27}$	$1{,}617\times10^{-27}$	$6{,}001\times10^{-15}$	1.32×10^{-15}	1.673×10^{-27}	10^{-15}

A6.5 Assessment of possible distortion of fundamental constants due to integral effects

As has been shown in Table and in the calculations of this appendix, the theoretical mass values derived from the wave model are close to the experimental ones but have small, systematic discrepancies. Specifically, the discrepancy for the electron is minimal (≈0.4%), whilst for nucleons it reaches 3-4%. In this model, this discrepancy is not viewed as a flaw but as a ***consequence, indicating a difference between 'ideal' geometrical parameters and 'effective' quantities measured in experiments.***

If we adopt the form of Planck's constant proposed in this work as:

$$h_{th} = \frac{2\pi}{c^4}$$

then, using the experimentally determined value of ***h***, it can be seen that the corresponding value of the speed of light would have to be approximately ***312,054,866 m/s***, which ***is about 4% higher*** than the generally accepted value of ***299,792,458 m/s***. If this corrected speed of light is used in the quantisation coefficient, we obtain a mass value for the proton and neutron that is ideally suited to the experimentally determined mass of the neutron.

An interesting observation confirms this hypothesis. If we substitute the wave amplitudes M_0 obtained in the model as mass into the classical de Broglie formula, the numerical values of the wavelengths prove to be identical to the theoretical λ_0 only if we substitute into the de Broglie formula not the experimental Planck's constant, h_{exp}, but rather its theoretical expression from this model:

$$h_{th} = \frac{2\pi}{c^4}$$

This may indicate that the experimentally obtained value h_{exp} represents an averaged or 'effective' quantity. The source of this effect may lie in **the very definition of our mass standards**.

The modern system of atomic masses and, consequently, the calibration of fundamental constants, rely on **the carbon-12 ion**, which by definition has a mass of exactly 12 atomic mass units. However, the carbon-12 nucleus is not an elementary particle, but a **complex bound system of 6 protons and 6 neutrons**. Its mass is determined not merely by the sum of the masses of its constituent nucleons, but also includes the immense contribution of the **energy of their strong interaction** (the so-called mass defect).

Thus, **the standard for mass adopted is not a 'pure' elementary particle, but the result of their complex collective interaction**. The complexity of this reference structure, the averaging of contributions from numerous protons and neutrons with their different (according to experiment) masses and binding energy, is inevitably 'embedded' within the definition of the atomic mass unit.

Since all high-precision methods for measuring Planck's constant (such as the Kibble balance) are ultimately calibrated against macroscopic masses composed of such complex nuclei, the measured value hexp is also an **effective constant that reflects this structural complexity**, rather than a 'pure' geometrical quantity like $2\pi/c^4$, which would correspond to an idealised, single wave structure.

This explains why the model presented here, proceeding from 'ideal' principles for single particles:

- Yields an almost perfect match for a 'simple' particle – the **electron**, whose contribution to the definition of the mass standard is minimal.
- Shows a small but systematic discrepancy for 'complex' particles – the **nucleons**, whose structural peculiarities and interactions form the very basis of the mass standard and, consequently, of h_{exp}.
- Predicts that this discrepancy grows with the complexity of the particle (with increasing n), which is indeed observed when comparing the discrepancies for the proton and the neutron.

As a result, we are dealing with a closed system of physical measurements in which an 'error' or, more precisely, a 'structural effect' embedded in the definition of one of the fundamental quantities (mass via the carbon-12 ion) is translated to all other constants (including h_{exp}) that are measured using it. This makes a consistent, yet potentially inexact (relative to 'ideal' geometrical principles), picture of physical parameters inevitable.

As for the wavelengths and sizes of elementary particles, there are still many uncertainties. Until recently, the size of the neutrino was considered to be smaller than 10^{-22} m, and only recently has its **quantum extent** been obtained: ≥ 6.2 picometres (6.2×10^{-12} m), which is already comparable to the calculated size of 9.715×10^{-11}. To compare the values calculated here, it is the size of the quantum extension that will be best suited. Exactly it defines the wave structure of the particle, its size.

Here are links to recent studies that discuss the quantum extent of neutrinos:

1. **Nature (2025)**: A lower limit on the spatial extent of the neutrino wave packet, 6.2 picometers, has been established for the first time. This value is much larger than the size of an atomic nucleus and reflects the quantum mechanical nature of neutrinos, where "size" refers to the spatial uncertainty of their wave packet rather than a physical measurement. InFocus Mail+1IXBT+1
2. **Phys.org**: The study confirmed that the spatial width of the neutrino wave packet is at least 6.2 picometres, which is thousands of times the size of an atomic nucleus. This discovery has important implications for understanding the quantum properties of neutrinos and could influence the development of more efficient neutrino detectors. phys.
3. **CERN Courier**: The BeEST experiment using unstable beryllium-7 nuclei has set the limit on the spatial localisation of the neutrino wave packet at 6.2 picometres. This value is more than 1000 times the size of an atomic nucleus and provides new constraints on the quantum properties of neutrinos. cerncourier..

Appendix 7: Comparison of the Proton's Wave Structure with Experimental Data (Hard Core Effect and Charge Radius)

A7.1. Discrepancy Between Calculated and Experimental Radii

According to the wave model (Appendices 3 and 7), the proton is a structure consisting of five half-waves with a characteristic diameter of approximately 6 fm. Consequently, the size of a single half-wave is about 1.2 fm. The central region of the structure, corresponding to one half-wave, is characterized by maximum energy density and can be regarded as the primary resonance zone determining the particle's properties. Its radius is:

$$R_{calc} \approx 0{,}6 \text{ fm}$$

At the same time, the experimentally measured charge radius of the proton is:

$$R_{exp} \approx 0{,}84 \text{ fm}$$

The difference between these values is:

$$\Delta R \approx 0{,}24 \text{ fm}$$

Within this model, this discrepancy is interpreted not as an error, but as a manifestation of a fundamental limitation related to the interaction structure in the proton's central region.

A7.2. The "Hard Core" Effect

In nuclear physics, it is well known that at distances of about 0.4–0.5 fm between nucleons, strong repulsion occurs. An inner region with a radius of approximately 0.2–0.3 fm is often interpreted as a **"hard core."** In the proposed model, this region corresponds to the zone of maximum energy density at the center of the wave structure. It possesses the following properties:

- A sharp increase in interaction strength;
- Inaccessibility to direct "probing";
- A shift in the nature of interaction compared to the periphery.

To describe this area, the following concept is introduced: **The Region of Informational Opacity** — a zone where the standard description of interactions ceases to be applicable. Within this model, it is viewed as a local analog of a **black hole**, understood as a region of informational inaccessibility. The region of informational opacity is an invariant element of the fractal structure. While the physical mechanism of its formation changes across different scales, its observable property—the limitation of information transfer—remains constant. Consequently, such regions at every level can be interpreted as analogs of black holes.

A7.3. Formation of the Measured Radius

Section 7 demonstrates that the existence of minimum scales is necessitated by the finite speed of interaction propagation. Within this model, it is assumed that:

1. A region inaccessible to direct interaction exists at the center of the wave structure;
2. Its size depends on the system's parameters (energy, mass, state of motion);
3. Attempts to probe this region lead to energy redistribution, including particle production.

This leads to the fact that the experimentally measured radius is determined not by the geometric boundary of the structure, but by the **effective interaction region**. Thus, the observed radius can be represented as the sum of two contributions:

$$\mathrm{R}_{exp} = \mathrm{R}_{\mathrm{wave}} + \mathrm{R}_{\mathrm{core}}$$

Where:

- $R_{wave} \approx 0{,}6$ fm — the radius of the central resonance region;
- $R_{core} \approx 0{,}24$ fm — the contribution of the informational opacity region.

This yields:

$$\mathrm{R}_{exp} \approx 0{,}6 + 0{,}24 = 0{,}84\ \mathrm{fm}$$

Thus, the discrepancy between the calculated and experimental values finds its interpretation within the model.

A7.4. Interpretation of Quark Positions (Focusing Effect)

Within the model, quarks are viewed not as point-like objects but as localized standing wave configurations. Furthermore:

- The characteristic distance between these configurations is determined by the half-wave scale (~1.2 fm);
- The total extent of the structure exceeds the experimentally observed radius.

At first glance, this contradicts experimental data where quarks appear localized within ~0.84 fm. The model explains this through the specifics of the measurement process:

1. **Relativistic Projection:** At high interaction energies, energy density redistribution occurs, leading to an effective "compression" of the observed structure.
2. **Interaction Focusing:** The non-uniform energy density distribution within the proton concentrates the probe's trajectories toward the region of maximum density.
3. **Effective Localization:** As a result, the experiment captures not the full structure, but its projection onto the region of intense interaction.

Thus, the observed quark distribution can be interpreted as an effective image formed by the interaction process, rather than a direct reflection of the geometric structure.

Conclusion to the Appendix

The coincidence of the value $R_{core} \approx 0.24$ fm with characteristic scales known from nuclear physics serves as indirect confirmation of the wave model's applicability. In this interpretation:

- The proton's charge radius is not a rigid boundary,
- but an **effective interaction radius**,
- formed by accounting for the central region inaccessible to direct probing.

This aligns with the concept that observed particle parameters depend on the measurement method and reflect not only their internal structure but also the nature of their interaction with an external field.

Appendix 8: Scaling between the neutron and the Milky Way.

Based on the equation given in chapter "8 Fractality of the Universe structure.", the parameters of the neutron analogue will be calculated on a larger scale. The obtained values will be compared with the known parameters of the Milky Way galaxy. As Planck's constant and neutron parameters the values obtained on experience are taken so that they better agree with the data obtained on experience for galaxies.

The size of the Milky Way:

- **Diameter:** estimates range from 100,000 to 120,000 light-years (about 30-37 kiloparsecs). znanierussia.ru
- **Thickness:** about 1,000 light years. techinsider.ru

The mass of the Milky Way:

- **Total mass:** estimates range from 1 to 2 trillion (10^{12}) solar masses, including dark matter. ru.wikipedia.org
- **Mass of the stellar component:** about 50-60 billion (5-6 × 10^{10}) solar masses.

A8.1 Size scaling

When going from the neutron to the Milky Way, the level changes towards a lower frequency, i.e. n=–1. Then the scaling of the radius is as follows:

$$R_{gal} = R_0 \cdot \left(\frac{1}{c^4}\right)^n$$

From Appendix 7, the size of a neutron is approximately 1.648×10^{-13}.

Substituting the values:

$$R_{gal} = 1{,}648 \cdot 10^{-13} \cdot \left(\frac{1}{c^4}\right)^{-1}$$

$$R_{gal} = 1{,}648 \cdot 10^{-13} \cdot (1.2345679 \times 10^{-34})^{-1}$$

$$R_{gal} = 1{,}335 \cdot 10^{21}$$

The diameter of the Milky Way in metres:

- **Minimum estimate:** ≈ 9.46×10^{20} m
- **Maximum score:** ≈ 1.14×10^{21} m

The calculated radius of the Milky Way within this model differs slightly from the values accepted in astrophysics (~ 1×10^{21} m). This may be a consequence of several factors:

1. **Experimental error** in determining the size of the galaxy.
2. **The effect of speed of movement** on the size of objects, which is important to consider when comparing scales.

3. **The calculation methods in astrophysics** are based on models of the expansion of the Universe, which may introduce additional deviations.

It is also worth noting that the calculated theoretical size turned out to be slightly larger than that known from astrophysics, which is exactly how it should be. Baryonic matter is a consequence of changes in the internal redistribution of energy in standing waves on a galactic scale and will eventually gravitate towards the centre of the black hole, which will reduce its visible/occupied size. Which is, in fact, what is observed.

A8.2 Mass scaling

Let us take the neutron mass calculated in Appendix 7 as:

$$m_n = 1.617 \cdot 10^{-27} kg$$

Then the mass of the galactic analogue of a neutron is:

$$M_{gal} = M_0 \cdot \left(\frac{1}{c^4}\right)^{2n}$$

$$M_{gal} = 1.617 \cdot 10^{-27} \cdot (1.2345679 \times 10^{-34})^{-2}$$

$$M_{gal} = 1{,}061 \cdot 10^{41} kg$$

Milky Way mass derived from observations:

- Lower estimate: **1.99×10^{42} kg**
- Upper estimate: **3.98×10^{42} kg**

The mass was slightly less than expected (~ **3×10^{42}** kg). This may be due to several factors:

1. **Measurement errors** arising when determining the mass of a galaxy.
2. **Dependence of mass on speed of motion**, which can play an important role when comparing objects at different scales.

It is also important to remember that when an object's speed increases, its size decreases and its mass increases. This is something we can observe in practice.

A8.3 Analysing the results obtained

The calculated values of the radius and mass of the Milky Way galaxy, obtained on the basis of the fractal coefficient, showed a difference, but still an interesting approximation to the data of modern astrophysics. The radius calculated using the formula is $R = 1.335 \times 10^{21}$ m, which is comparable to the observed value of about 1×10^{21} m. The mass obtained taking into account the fractal coefficient is $M = 1.061 \times 10^{41}$ kg, while astrophysical estimates give a range of $(1.99–3.98) \times 10^{42}$ kg. Although these results differ, they are still quite close to those obtained experimentally. However, it should be noted that the results obtained experimentally are indirect, which does not exclude errors in approximate calculations.

The question of the accuracy of current measurement methods remains important. In quantum physics, the mass of particles is determined through interaction with fields and depends on the environment. If spatial structures have fractal properties, this can affect measurement results, introducing systematic errors.

The results obtained indicate that the current methods of mass and size estimation both at the microscale and at the level of galaxies may need to be revised taking into account the fractal structure of the Universe. This opens prospects for refining experimental data and for a deeper understanding of the fundamental processes that shape the world at all scales.

A8.4 Scaling the speed of light

$$C_{gal} = \frac{c_0}{\hbar^n}$$

$$C_{gal} = \frac{299792458}{1.2345679^{-1} \cdot 10^{34}}$$

$$C_{gal} = 3{,}70114145 \cdot 10^{-26}$$

This shows that the speed of light - the limiting speed of electromagnetic interactions - is much smaller at the level of galaxies than at our scale, corresponding to a more rarefied state of energy.

A8.5 The Fractal Structure of the Universe: Galaxies as Elementary Particles

Obtained calculated data on the Milky Way using standard physical formulas with a slight modification and using again known in physics constant - Planck's constant, can not be a simple coincidence. Of course, it would be possible to assume that it is just a coincidence, but if it was observed with only one parameter. But the fact that both parameters (mass and size) practically coincide already excludes the occurrence of coincidence. There is a strong possibility that the WORLD is fractal. The fact that for the Milky Way the fractalisation formula worked with astonishing accuracy suggests that the Milky Way is an analogue of the neutron. It's a very good match. This can now be used to study and describe the space around us. The Milky Way galaxy can be taken as a reference.

It remains to be seen how to explain the large number of different kinds of galaxies. Find out whether they are all analogues of elementary particles, or whether some of them arise as a result of their joint interactions.

A8.6 Analogy between spiral galaxies and neutrons

The Milky Way and the Andromeda galaxy have similar masses but different sizes. This may be due to their speed: at lower speeds the galaxy becomes larger, and at higher speeds it becomes more compact. This difference explains the observed differences in size and mass. Moreover, the sizes of galaxies are determined by the visible matter, which will only be observed if the elementary particle is accelerated. If there is no acceleration, it will be difficult to track the size of the particle, as visible matter may not be present, or may not be present in sufficient quantity to determine the true size of the structure. Spiral galaxies are of particular interest because their structure and mass distribution obey certain regularities. When considering galaxies formed as standing waves with an even number of nodes (charged particles), it is difficult to determine the real size of the structure formed. It will consist of alternating regions with increased and decreased energy density. In the regions with increased energy density there may be matter. Interactions with such structures can lead to the formation of various types of galaxies, which are only indirect manifestations of the basic structures.

The cases of spiral galaxies with larger masses than the Milky Way are interesting. For example, ISOHDFS 27 is a spiral galaxy with a mass four times that of the Milky Way, but its size has increased only slightly. This behaviour may indicate that its mass increases by a multiple of the neutron (proton) mass, while its size changes only slightly. This is already reminiscent of nuclear interactions: ISOHDFS 27 is an object similar to a helium nucleus, where the energy density is higher and the mass increases by a multiple of the neutron mass.

A8.6.1 Compact dwarf galaxies and electrons

While spiral galaxies can be compared to neutrons or their interactions with protons, compact dwarf galaxies can be analogues of electrons. The electron can be thought of as a standing wave with a region of higher energy density at its centre. It is in this region that matter can form, which is what is perceived as compact dwarf galaxies. It is worth keeping in mind that the size of an electron refers to its effective size, as determined in scattering experiments. Interestingly, the difference between the size of the electron and neutron nucleus is three orders of magnitude. If the size of the Milky Way is estimated to be 10^{20} - 10^{21} metres, the size of the electron's analogue should be of the order of 10^{17} - 10^{18} metres, which corresponds to the size of compact dwarf galaxies.

A8.6.2 Formation of additional galaxies

There are many galaxies in the Universe, which may not be analogues of elementary particles, but may be the results of interactions between elementary particles of galaxy sizes. As a result of interactions can be formed zones with increased energy density, and given that it will also be accompanied by acceleration processes, it will lead to the emergence of matter in areas with increased energy density, which will give birth to galaxies. Such galaxies may seem to be independent objects, but probably they are just a consequence of redistribution of energy between more fundamental structures.

Thus, analyses of the sizes and masses of galaxies, as well as their interactions, can provide insight into the fundamental structure of the Universe and its analogy to the microcosm.

Appendix 9: Calculation of resonance frequencies of macroobjects within the wave geometric model of matter.

Introduction

In the model of the wave structure of matter and fractal structure of the Universe, matter is considered as waves of energy. Everything is subject to resonant interaction. It is shown that there is a region of size $1/c^2$ at the centre (considered as a dimensionless quantity), which can be seen as the centre of mass of a particle, and the adjacent region will have a wave energy distribution around it, which can be interpreted as a wave function. This helps to explain why the existing physics, quite accurately describes the processes taking place in the surroundings. This approach is very convenient for describing the world, although it has some limitations, for example, it does not allow to describe what is happening beyond the boundary of the event horizon. Also this approach can help to carry out calculations of resonance frequencies for macroobjects, using which it will be possible to obtain the necessary information, for example, frequencies accompanied or caused by seismic activity.

A9.1 Macro-object as a particle

Since the matter of which macroobjects are composed is the result of wave processes of energy, the macroobject can be replaced by a representation of a wave process. The macro-object itself will be an analogue of the region $1/c_1^2$, where c_1 is the effective interaction velocity that would create an object with such dimensions.

In such a case, knowing the radius of the macroobject, one can find out the speed at which its analogue would be created as a whole wave. Knowing its effective interaction velocity, it is possible to calculate the charge of the object and the parameters of the particles that will be in resonance with it, which will allow, for example, to detect the effect of charge interaction or energy rotation and use it, for example, to repel from the macroobject.

If we have an object of radius R, we get a value for the interaction velocity:

$$c_1 = \frac{1}{\sqrt{2R}}$$

Knowing the effective rate of interaction, we obtain the expression from the formula for calculating the charge:

$$q_{mac} = \alpha \frac{6}{\pi} c_1^{-2} = \alpha \frac{12}{\pi} R$$

Using the formula for calculating the wavelength at a given interaction velocity, for a macroobject we can rewrite it in the form:

$$\lambda = {c_1}^{-1}\left(\frac{c_1}{2\pi}\right)^{-\frac{n}{5}},$$
$$1 \le n \le 4$$

At n>4, energy transfer into gravitational waves will be observed, which will lead to seismic activity.

To calculate the frequency we use the standard formula:

$$f = \frac{c}{\lambda}$$

Here already the standard speed of light is used as ***c***, because we have to get resonance with our interaction speed.

A9.2 Calculation for Earth

Using the formulas above, we calculate the parameters for the Earth.

Earth radius R 6371≈× 10³ m

$$c_1 = \frac{1}{\sqrt{2 \cdot 6371 \times 10^3}} \approx 2{,}8014391888460448626359695257632 \times 10^{-4}$$

$$c_1^{-1} = \sqrt{2 \cdot 6371 \times 10^3} \approx 3{,}5695938144276303639707523697275 \times 10^3$$

$$\frac{|c_1|_{num}}{2\pi} \approx (1{,}34847)^5 \times 10^{-5} = (0{,}134847)^5$$

$$q_{mac} = \alpha\frac{12}{\pi}R = \frac{12}{\pi \cdot 137}6371 \times 10^3 \approx 1{,}7763085706950045841394265941 44 \times 10^5\ C$$

According to current physical understanding, the Earth has a negative electric charge of approximately **600,000 coulombs (C)**. This charge is due to the existence of a global electric field between the Earth's surface and the ionosphere, where the Earth is negatively charged and the ionosphere is positively charged. The average strength of this field near the Earth's surface is about **130 V/m**. ru.wikipedia.org ZFTSh, MIPT

It was this discrepancy between the values of the charge obtained by me and the one obtained in physics that made me think about the essence of the constant fine structure. This led to the formation of the chapter "7.6.7 On the nature of the constant fine structure", in which its essence is explained. For the Earth the influence of gravitation, caused by the same, in the manifestation of charge will be much less, so in this case there is a discrepancy. In the future I hope to find the calculated value of this coefficient depending on geometry.

Now let's calculate wavelengths and frequencies for different numbers of nodes, which will create different variants of interactions at resonance with the Earth in this case.

$$c_1^{-1}\left(\frac{c_1}{2\pi}\right)^{-\frac{n}{5}},$$
$$f = \frac{c}{c_1^{-1}\left(\frac{c_1}{2\pi}\right)^{-\frac{n}{5}}},$$
$$1 \leq n \leq 4$$

n=1

$$\lambda = 3{,}56959381 \times 10^3 \cdot (0{,}134847)^{-1} \approx 26{,}47143659\ \times 10^3\ m,$$
$$f = \frac{c}{\lambda} \approx \frac{299\ 792\ 458}{26{,}47143659\ \times 10^3} \approx 11\ 325{,}12989919\ Hz$$

n=2

$$\lambda = 3{,}56959381 \times 10^3 \cdot (0{,}134847)^{-2} \approx 196{,}30719697 \times 10^3\ m,$$
$$f = \frac{c}{\lambda} \approx \frac{299\ 792\ 458}{196{,}30719697 \times 10^3} \approx 1\ 527{,}1597915\ Hz$$

n=3

$$\lambda = 3{,}56959381 \times 10^3 \cdot (0{,}134847)^{-3} \approx 1\ 455{,}77726586 \times 10^3\ m,$$
$$f = \frac{c}{\lambda} \approx \frac{299\ 792\ 458}{1\ 455{,}77726586 \times 10^3} \approx 205{,}932916408677\ Hz$$

n=4

$$\lambda = 3{,}56959381 \times 10^3 \cdot (0{,}134847)^{-4} \approx 10\,795{,}770509 \times 10^3\ m,$$

$$f = \frac{c}{\lambda} \approx \frac{299\,792\,458}{10\,795{,}770509 \times 10^3} \approx 27{,}769435979588\ Hz$$

At frequencies lower than 27 Hz there will be energy transfer to the inner region of the macroobject, which can cause seismic activity. It can also be said that seismic activity will be accompanied by the emission of energy at frequencies of 27 Hz and below. This can be used as a signal of the beginning of seismic activity.

A9.3 Table of resonant wavelengths and frequencies for the Earth

№ node (n)	Wavelength λ_0, m	Frequency f, Hz	Nature of interaction
1	$26{,}47143659 \times 10^3$	11325,129899	neutrino
2	$196{,}30719697 \times 10^3$	1527,159792	electron
3	$1455{,}7772658 \times 10^3$	205,932916	neutron
4	$10795{,}770509 \times 10^3$	27,769436	proton

A9.4 Conclusion

In this paper it is shown that using the geometrical approach of the wave model of matter, it is possible to calculate the resonance frequencies of macroobjects, including such as the Earth, without involving empirical data.

It has been shown that resonant frequencies corresponding to different numbers of nodes (n) can be used as indicators of different modes of interaction with a macroobject, from safe energy resonance to the transition to the region of gravitational disturbances and possible seismic activity.

These results confirm that the wave approach underlying the 'Model of the Wave Structure of Matter and fractal structure of the Universe' is applicable not only to the microcosm, but also to macroobjects, and can provide useful information about the structure and dynamics of interactions in nature.

The obtained dependences can be used both for further theoretical analyses and as a basis for the construction of practical devices interacting with mass at resonant frequencies.

The proposed calculations can be used as a basis for the development of technologies for controlling gravitational interaction and monitoring geophysical processes, as well as for the creation of means for wireless energy transfer at a distance with a high efficiency factor.