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A New Theory Exploring the Internal Structure of Quarks

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Abstract

This paper introduces a novel theoretical model that reimagines the internal structure of quarks as superfluid vortices formed during the Quark Epoch of the Big Bang. The proposed theory challenges the traditional view of quarks as point-like entities without internal structure, offering instead a hydrodynamic perspective that aligns with the principles of quantum chromodynamics (QCD). By considering quarks as vortices in a frictionless superfluid vacuum, the model provides new insights into their mass, charge, spin, and interactions. The formalism presented in this work utilizes hydrodynamic principles to model quarks as irrotational circular vortices, calculating key properties such as charge radius, mass, and density. The calculations are grounded in the application of vortex dynamics, including the evaluation of circulation, vorticity, and the balance of forces within the quantum fluid. The resulting quark radius and mass are shown to be consistent with known experimental ranges, providing a strong validation of the vortex-based formalism. The theory also explores the implications of this vortex model on the stability of quarks within protons and neutrons, and how quark-antiquark pairs (mesons) and three-quark structures (baryons) can be understood as interactions between these vortices. Additionally, the model predicts specific quark properties such as charge radius and density, which are consistent with experimental observations and current understandings of subatomic particle physics. Furthermore, this approach elucidates the strong force's role as an interaction between these vortices, mediated by gluons in the quantum fluid. The proposed model not only aligns with existing experimental data but also paves the way for further exploration into the complex behaviors of quarks and their role in the fundamental structure of matter.

Keywords

Quark, Vortex, Proton, Superfluid Vacuum, Quantum Chromodynamics

(QCD), Gluon, Strong Force

1. Introduction

The proton, derived from the Greek word *πρῶτον* (proton = first), is a fundamental subatomic particle with a positive electric charge of one elementary unit (1.602 × 10^{-19} coulomb). It possesses a diameter of approximately 1.5 × 10^{-15} meters and a mass of 938.27231(28) MeV/c^2 (1.6726 × 10^{-27} kg), or about 1836 times that of an electron.

Found within the nuclei of atoms, the proton is considered a composite particle, consisting of three subatomic particles known as quarks. In the diverse realm of known particles, only the proton, antiproton, electron, positron, neutrinos, and photons appear to be stable. All other particles undergo decay. Notably, the free neutron, which is unbound in a nucleus, decays within a 15-minute half-life. The Grand Unified Theory (GUT) of particle physics, which aims to consolidate all physical theories into a single model, predicts that protons should decay with a half-life of approximately 10^{32} years. However, recent measurements suggest that the proton's half-life exceeds 5 × 10^{33} years. The enduring stability of the proton and its antiparticle as the only stable hadrons remains a perplexing enigma.

The proton has a complex and dynamic internal structure. Despite being a basic building block of matter, much about its internal workings is still a subject of research and discovery.

Protons are composed of three valence quarks—two "up" quarks and one "down" quark. These quarks are held together by the strong force, mediated by gluons.

These are the force-carrying particles of the strong interaction (Quantum Chromodynamics, QCD). Gluons bind quarks together, enabling the proton to maintain its integrity.

In addition to the three valence quarks, protons contain transient quark-antiquark pairs known as sea quarks, which continuously form and annihilate.

The proton has a spin of 1/2. Understanding how this spin arises from its constituents—quarks, antiquarks, and gluons—remains a complex puzzle.

Experiments in the 1980s revealed that quark spins contribute only about a quarter of the proton's total spin, leading to the "spin crisis." The rest is thought to come from gluon contributions and quark-gluon interactions.

Protons carry a positive electric charge of +1e, counterbalanced in atoms by the negative charge of electrons.

The proton has a mass of approximately 938 MeV/c^2 (1.6726 × 10^{-27} kg), much greater than the sum of the masses of its constituent quarks. This mass arises from the strong interaction energy within the proton.

Measuring the proton's charge radius has led to conflicting results, known as the "proton radius puzzle." Different experimental methods (electron scattering vs. muonic hydrogen spectroscopy) yield slightly different measurements.

High-energy scattering experiments have mapped the momentum and spatial distributions of quarks and gluons within the proton, revealing complex internal structures influenced by the proton's spin and other factors.

Probing protons with high-energy electrons to study the distribution and behavior of internal quarks and gluons.

Quantum Chromodynamics (QCD) is the fundamental theory describing the interactions between quarks and gluons. QCD is complex and requires advanced computational methods, such as lattice QCD, for detailed predictions.

The strong interaction is described by Quantum Chromodynamics (QCD), which encompasses the dynamics of quarks and gluons. The theory is characterized by two fundamental properties: asymptotic freedom and confinement. At high energies or short distances, quarks interact weakly with each other, behaving almost as free particles; this is known as asymptotic freedom. At low energies or large distances, quarks are tightly bound together by gluons, forming hadrons. Quarks cannot exist in isolation; they are always confined within larger particles.

QCD is mathematically complex, making exact analytical solutions difficult to obtain. The interactions between quarks and gluons are highly nonlinear due to the self-interactions of gluons, leading to a rich and intricate structure. To make precise predictions, advanced computational methods are employed. At high energies, where the coupling constant of QCD becomes small, perturbation theory is used to make calculations. This approach has been successful in describing high-energy processes such as deep inelastic scattering and jet production in particle colliders.

At low energies, where the coupling constant is large, perturbative methods fail. Instead, lattice QCD is used, which involves discretizing space-time into a lattice and performing numerical simulations. This method allows for non-perturbative calculations of hadronic properties and has provided deep insights into phenomena such as quark confinement and hadron masses.

Lattice QCD has been instrumental in calculating fundamental properties of hadrons, such as the mass spectrum of mesons and baryons, the structure of the nucleon, and the dynamics of quark-gluon plasma. These calculations require immense computational resources and are often performed on supercomputers.

QCD has been extensively tested and verified through experiments in high-energy physics. Particle colliders, such as the Large Hadron Collider (LHC) at CERN and the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, provide experimental data that can be compared with QCD predictions. Heavy ion collisions at RHIC and the LHC create conditions of extremely high temperature and energy density, similar to those in the early universe. These collisions produce a quark-gluon plasma, a state of matter where quarks and gluons are deconfined. Studying this plasma helps to understand the properties of the strong interaction under extreme conditions.

Deep inelastic scattering experiments have probed the internal structure of protons, revealing the distribution of quarks and gluons. These experiments have confirmed the predictions of QCD regarding the behavior of partons (quarks and gluons) within the proton.

Despite its successes, QCD remains an active area of research with many open questions. The behavior of QCD matter at high baryon densities, relevant for neutron stars and heavy ion collisions, is still not fully understood. Research in this area aims to uncover the phase diagram of QCD. While the confinement explains why quarks can move independently at extremely high energies, understanding the precise mechanism of quark confinement remains a major challenge. Various models, such as the dual superconductivity model, are being investigated to explain this phenomenon.

While significant progress has been made in understanding the proton's structure, many questions remain. Ongoing experiments and theoretical advancements continue to provide new insights into this fundamental particle. The complexity of the proton's internal structure underscores the rich interplay of forces and particles that define the subatomic world.

In this article a new theory about the structure of quarks and proton and neutrons are presented according to which the quarks are superfluid vortices formed during the epoch of quark during the big bang.

2. The Structure of the Quark

Quarks are fundamental particles that are the building blocks of hadrons, such as protons and neutrons. They are among the most elementary entities in the universe and cannot be broken down into smaller components. Quarks are fundamental particles recognized as the essential building blocks of matter in the universe. Unique among particles, quarks engage in all known fundamental interactions within the framework of the Standard Model (SM).

According to this model, the material world consists of two primary types of particles: quarks and leptons, along with their corresponding antiparticles. Leptons include neutrally charged particles like the neutrino and those with a charge of one unit, such as the electron, muon, and tau.

Quarks, on the other hand, are elementary particles carrying fractional electric charges of either 1/3e or 2/3e. Like electrons, quarks are spin-1/2 particles, classifying them as fermions.

The strong interactions between quarks and gluons are described by Quantum Chromodynamics (QCD), a gauge theory integral to the SM.

A distinctive characteristic of QCD is the "color charge" carried by quarks and gluons, preventing their isolation from hadrons. This phenomenon, known as "color confinement," ensures that hadrons, rather than quarks or gluons, are the smallest particles that can be observed independently.

Another notable feature of QCD is that as the energy or momentum transferred between quarks increases, their interactions become weaker. This property allows scientists to probe the structure of quarks through high-energy hadron-hadron or electron-hadron scatterings, providing a clearer view of these minute, colored entities.

Discovering smaller fundamental particles than quarks or uncovering internal structures within quarks would necessitate new physics beyond the Standard Model. Such findings could significantly alter our understanding of matter. Investigating these possibilities represents the cutting edge of modern high-energy physics, encompassing both theoretical and experimental domains.

3. The Formation of the Quarks

According to standard model quarks are considered pointlike objects, meaning they have no discernible internal structure or size.

The Standard Model provides a robust framework for understanding the interactions between fundamental particles, including quarks and the forces acting upon them. However, this model does not fully predict the intricate structure of quarks.

In previous article, we presented a new approach to modeling subatomic particles like the electron as vortices within a fluid medium offers a unique perspective on fundamental particles [1].

According to quantum field theory, the vacuum is not an empty void but a dynamic field filled with quantum mechanical zero-point energy. This energy arises from the fluctuating quantum fields that permeate the Universe. The vacuum behaves like a frictionless superfluid with extremely high thermal conductivity, extending everywhere without any defined size, shape, center, or direction. Consequently, vacuum energy manifests in tangible, measurable ways, and its characteristics can be detected as actual physical phenomena [2] [3].

This superfluid vacuum is a fundamental aspect of the cosmos, playing a crucial role in the formation of elementary particles, such as quarks, during the Big Bang.

Immediately after the Big Bang, the energy density of the Universe was extremely high, causing intense fluctuations in the quantum fields. During the Big Bang, the Universe underwent rapid expansion and cooling, leading to the formation of elementary particles. As the Universe expanded and cooled, symmetries in the fundamental forces were broken, leading to the differentiation of particles.

Regions of high energy concentration within the quantum fluid led to the formation of vortices. These vortices are analogous to elementary particles such as quarks. The properties of these vortices—such as charge, spin, and mass—are determined by the dynamics of the quantum fluid.

The interaction of these vortices with the surrounding fluid and with each other defines their behavior. The superfluid nature of the vacuum plays a crucial role in particle interactions. The strong force that binds quarks together into protons, neutrons, and other hadrons can be viewed as the interaction between vortices mediated by gluons, which are excitations in the quantum fluid. The masses of particles may result from their interaction with the superfluid vacuum, similar to how particles gain mass through the Higgs mechanism.

The behavior of the quantum fluid would influence the distribution of matter, leading to the formation of galaxies, stars, and other large-scale structures.

The density of the universal quantum fluid is clearly not uniform throughout the Universe because it can be strongly compressed in several regions (e.g., galaxies, stars, black holes, and planets). In the normal state (free space), the abovementioned fluid is invisible.

This superfluid vacuum can support the formation of vortices, which are stable, localized structures within the fluid.

In the context of quark formation, a vortex in the superfluid vacuum can be visualized as a rotating region of the fluid. These vortices can be thought of as the physical manifestation of particles, with their properties arising from the dynamics of the fluid.

Studies indicate that quark-gluon plasmas, under certain conditions, exhibit superfluidity. This superfluid state is capable of forming vortices in response to external forces such as rotation and magnetic fields [4].

Magnetic and rotational vortices observed in superfluid quark matter provide a framework for understanding how such vortices could form in the early universe [5].

Laboratory experiments simulating cosmic string formation using superfluid helium-3 (^3He) suggest that superfluid vortices can indeed form during rapid transitions to the superfluid state, analogous to conditions post-Big Bang.

The creation of vortices in neutron-irradiated superfluid helium-3 further supports the idea of vortex formation during rapid phase transitions [6].

Several theoretical models support the idea of particles as vortices in a superfluid vacuum:

Spinor Model proposed by Elie Cartan, describes elementary particles as spinors, which can be thought of as vortex-like structures in spacetime. This model links the properties of particles to the geometric properties of the surrounding spacetime [7].

Vortex Model by Frank Wilczek proposed that elementary particles, including quarks, are vortices in a superfluid-like medium called the "aether." This medium, devoid of viscosity, supports the formation of stable vortices that give rise to the observed properties of particles [8].

Topological Defect Theory describes particles as topological defects or vortices in a superfluid medium. It was developed to explain defects in the early universe, such as cosmic strings and monopoles, and can also be applied to quark formation [9].

4. The Formation of Quarks from the Superfluid Vacuum as Vortices

We propose that quarks can be envisioned as irrotational circular vortices within a frictionless superfluid vacuum. This quantum fluid was formed during the Big Bang and extends throughout the Universe. This vortex model was discussed extensively to explain the electron's attributes, including spin and charge, wave-particle duality, and can be applied to the quark and be derived using hydrodynamic laws [10] [11].

Quarks were formed during the Quark Epoch of the Big Bang, which occurred approximately between 10^{-12} seconds to 10^{-6} seconds after the Big Bang. During the Quark Epoch, the universe had cooled down enough from the extreme temperatures of the initial moments (but was still extremely hot), leading to the formation of quarks as stable vortices within the quantum fluid. However, it was still too hot for them to bind together to form protons and neutrons. Quarks existed in a quark-gluon plasma, a state where they were free and not confined within particles like protons and neutrons. As the universe continued to expand and cool, it transitioned from the Quark Epoch to the Hadron Epoch, when quarks began to combine to form hadrons, such as protons and neutrons.

The vortex remains stable if the central negative suction point does not have sufficient energy to drag virtual particles to the speed of light, creating a balance that maintains the vortex. The superfluid vacuum accommodates rotational motion by forming a lattice of quantized vortices, where each vortex core breaks the topological constraint against rotational motion.

The spiral arms of the quark vortex consist of smaller vortices, which correspond to interactions with the Higgs field. These Higgs particles gain mass through their motion within the vacuum. The rotation of the quantum fluid causes a Coriolis effect, directing the flow towards the vortex center and resulting in vortex tubes composed of rotating virtual particles.

The strong force, which binds quarks into protons, neutrons, and other hadrons, can be viewed as interactions between vortices mediated by virtual photons named gluons, which are excitations within the quantum fluid.

The concept of quark formation from the superfluid vacuum involves viewing elementary particles, including quarks, as manifestations of vortices within a superfluid medium. This perspective offers a novel approach to understanding the fundamental nature of quarks and their interactions.

The properties of the quark, such as mass and charge, emerge from the characteristics of the vortex. The mass of the quark can be associated with the energy contained within the vortex. The mass of a quark is the amount of fluid-like virtual photons with a certain density that passes in 1 second.

The spin, or intrinsic angular momentum, of the quark is related to the rotational motion of the superfluid around the vortex core. Spin is like a vector quantity; it has a definite magnitude and a "direction." In order to spin, it should be composite, spinning around its own axis, producing tiny magnetic fields independent of those from its orbital motions.

In quantum chromodynamics (QCD), quarks carry a property called color charge, which is analogous to electric charge in electromagnetism but operates under the strong force. This color charge can be interpreted as arising from the specific configuration and dynamics of the vortex in the superfluid vacuum.

Viewing quarks as vortices in a superfluid vacuum offers new insights into their behavior and interactions. The strong force, which binds quarks together within protons and neutrons, can be understood as the interaction between vortices in the superfluid vacuum. The confinement of quarks within hadrons arises naturally from the dynamics of these vortices.

In high-energy environments, such as those created in particle colliders, the superfluid vacuum can transition into a quark-gluon plasma. In this state, quarks and gluons (the carriers of the strong force) move freely, corresponding to a state where the vortices in the superfluid vacuum are highly excited and interacting.

5. Attributes of a Quark Vortex in the Superfluid Vacuum

A quark is an elementary particle characterized by a vortex shape. It consists of a rotating core moving at the speed of light, with spiral arms called gluons. These gluons are composed of a flow of virtual photons.

The distribution of energy within these vortices influences their mass, charge, and spin. The vortex structure of quarks has observable physical effects, such as their interactions within protons and neutrons.

When considering vortices within a superfluid vacuum as models for quarks and other elementary particles, several attributes come into play. These attributes help define the properties and behaviors of the vortices and, by extension, the particles they represent.

These attributes are:

Rotation direction: The clockwise and counter-clockwise rotations of vortices in a superfluid vacuum offer a powerful framework for understanding the nature of elementary particles and their interactions. By associating these rotational directions with specific attributes such as spin and energy dynamics, we can model quarks and other particles in a way that provides new insights into the fundamental forces of the universe. This approach not only enhances our understanding of particle physics but also opens up new avenues for exploring the deep connections between quantum mechanics and the structure of spacetime (**Figure 1**).

Figure 1. Clockwise Rotation (left) and Counter-clockwise Rotation (right).

This is important aspect that allows the quark and antiquark to be connected together to form the meson.

Charge positive: and negative down (whirlpool)

There are two types of quark vortices. The first type is similar to a whirlpool, where the flow moves from the periphery to the center. In such a vortex, centripetal forces prevail, like in the case of the electron and the down quark in the proton. The second type is akin to a tornado, where the flow moves from the center (apex) to the periphery. In this type of vortex, centrifugal forces prevail, similar to the positron and the up quark (**Figure 2**).

Figure 2. Artistic illustration of up quark (left) and down quark (right) [10].

Spin value: +1/2 or −2/3 and vorticity ratio between the periphery and the center. The spin is the rate of rotation between the boundaries and the center of the vortex. When the center complete two orbital rotation in relation to the boundaries the spin is considered to be 1/2. Similar behavior is observed in different spiral galaxies.

Hence the magnitude of the spin quantum number is an intrinsic attribute of a particle related to the relation between the numbers of torque of the core of the vortex to the numbers of torque in the external part. A spin 1/2 particle needs *two* full rotations ($2 \times 360^\circ = 720^\circ$) of the core until it is again in the same state of complete rotation in the boundaries of the vortex. While a spin 2/3 indicates that the core rotates three full rotation and the boundaries two full rotation in one cycle.

Magnetic spin direction: Though not typically emphasized for quarks, could correspond to their magnetic moments. Magnetic force which is attractive in the opposite polarity, expressed by spin value −or +2 (**Figure 3**).

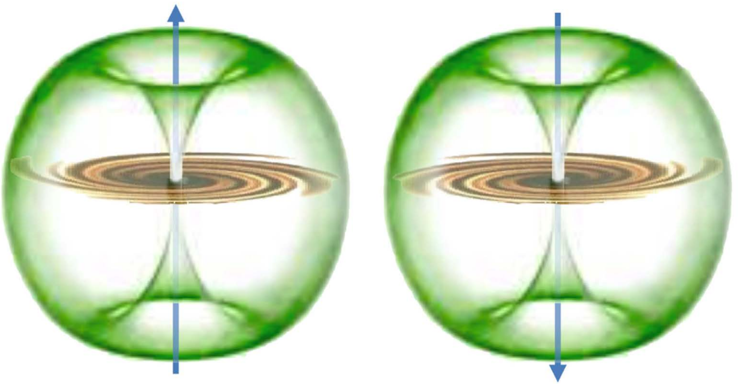

Figure 3. Negative magnetic spin (left) and positive magnetic spin (right) [12].

Colour charge: The balance between the flow from the periphery and the flow perpendicular in the center can be positive, negative, or neutral. It is positive if the centripetal force is greater than the centrifugal force. As a result, the virtual photons that reach the center of the vortex will be irradiated perpendicular to the vortex plane, similar to Hawking radiation in a black hole (Figure 4).

Figure 4. Quarks present in radioactive elements (left), Negative quark where the centripetal force prevails without radiation from the center (middle) . Neutral quark where the centripetal and centrifugal forces are equal (right).

Energy Density: This relates to the electric charge distribution of the quark. The electric charge density in the core of the d-quark is less than the vacuum density, while the core density of the u quark is greater than the vacuum density. Furthermore, the charge density is inversely related to the radius of the vortex. Therefore, if the vacuum density is ρ and the vortex core density is ρ_0. Then the electric charge density would be:

$$q = \rho_0 - \rho/2\pi r\rho_0$$

The charge density is positive if $\rho_0 > \rho$. The charge density is negative if $\rho_0 < \rho$. The electric charge density determines the direction of the gluon flow and the nature of attraction and repulsion interactions.

Stability: Stability determines whether the quark can exist independently or as part of a larger particle, such as a proton or neutron. A quark's stability is influenced by the balance of forces acting upon it, including the strong force mediated by gluons. If a quark is unstable, it will quickly combine with other quarks to form a stable particle. For instance, the down quark and up quark combine with other quarks to form protons and neutrons, which are stable particles found in atomic nuclei. The energy density, electric charge distribution, and interactions with other quarks and gluons all play a role in determining a quark's stability.

Interaction with Other Vortices: This describes the strong force interactions between quarks, which can be attractive, repulsive, or neutral. Quarks interact via the exchange of gluons, which carry the strong force. These interactions are responsible for binding quarks together to form larger particles like protons and neutrons. The nature of these interactions depends on the color charge of the quarks and the balance of forces within and between the vortices. Attractive interactions occur when the color charges complement each other, leading to the formation of stable particles. Repulsive interactions occur when similar color charges interact, causing the quarks to repel each other. Neutral interactions occur when the forces are balanced, resulting in no net attraction or repulsion.

Flow Patterns:

The flow patterns in the vortex are analogous to the distribution of gluons and the strong force field around quarks.

These patterns describe how the virtual photons (gluons) move and interact within the vortex, influencing the overall behavior and interactions of the quark.

The distribution and dynamics of these flow patterns are critical in understanding the strong force that binds quarks together in larger particles such as protons and neutrons.

See Table 1.

Table 1. Here is the comparison of the six types of quarks with the vortex attributes presented in a table.

Quark Type	Charge	Mass	Spin	Colour Charge	Stability	Vortex Attributes
Up (u)	+2/3e	~2.3 MeV/c^2	1/2	Red, Green, Blue	High (in protons and neutrons)	Positive vortex charge, low energy density, positive spin, less dense core, high stability, attractive interaction with down quarks.
Down (d)	−1/3e	~4.8 MeV/c^2	1/2	Red, Green, Blue	High (in protons and neutrons)	Negative vortex charge, low energy density, negative spin, less dense core, high stability, attractive interaction with up quarks.
Charm (c)	+2/3e	~1.27 GeV/c^2	1/2	Red, Green, Blue	Less stable (in heavier particles)	Positive vortex charge, high energy density, positive spin, denser core, less stable, forms charmed mesons and baryons.
Strange (s)	−1/3e	~96 MeV/c^2	1/2	Red, Green, Blue	Medium (in strange particles)	Negative vortex charge, intermediate energy density, negative spin, intermediate density core, less stable, forms strange mesons and baryons.
Top (t)	+2/3e	~173 GeV/c^2	1/2	Red, Green, Blue	Very unstable (decays quickly)	Positive vortex charge, very high energy density, positive spin, very dense core, highly unstable, decays before forming stable hadrons.
Bottom (b)	−1/3e	~4.18 GeV/c^2	1/2	Red, Green, Blue	Less stable (in heavier particles)	Negative vortex charge, high energy density, negative spin, dense core, less stable, forms bottom mesons and baryons.

Understanding these attributes provides a comprehensive view of how vortices in a superfluid vacuum can model the complex behaviours and properties of quarks and other elementary particles. This approach offers new insights into the fundamental nature of matter and the underlying dynamics of the universe.

6. Quark Gluon Interaction

The hydrodynamic model of quarks as vortices within a superfluid vacuum provides a novel perspective on their internal structure and interactions. In fluid dynamics and particularly in the study of superfluid vortices, the mechanism of vortex attraction can be understood through the concept of vortex interaction and the induced flow fields.

Each vortex in a superfluid generates a circulating flow field around its core. When two vortices are present in the same fluid, each vortex induces a flow field that influences the other. The velocity induced by one vortex at the position of the other vortex can cause motion and interaction between the two vortices. The direction and strength of the flow around each vortex are determined by the circulation (vorticity) of the vortices.

The system of vortices tends to evolve towards a state of lower energy. When two vortices with like-sign vorticity approach each other, the kinetic energy associated with their induced flow fields can be minimized by moving closer together, leading to an attractive interaction.

The flow fields around each vortex generate streamlines that correspond to the gluons that wrap around the vortices. The interaction of these streamlines creates regions of varying pressure. Lower pressure regions form between the vortices, pulling them towards each other.

The hydrodynamic interaction between two vortices is governed by the Biot-Savart law, which describes the induced velocity field due to a point vortex. This interaction leads to complex dynamics where vortices with the same sign of circulation rotate around each other (**Figure 5**).

Figure 5. Artistic illustration of two vortices interaction with the same sign.

This process is well describe in the macro realm in the when two black holes collide.

Initially, the black holes orbit each other at relatively large distances. Over time, they lose energy through the emission of gravitational waves, causing them to spiral closer together. This phase can last for millions of years.

As the black holes draw closer, their orbital speed increases, and they emit more gravitational waves. Eventually, they reach a point where they merge into a single, larger black hole. This phase is incredibly rapid, lasting only a fraction of a second.

When two black holes come close enough to each other, their mutual gravitational attraction can lead to a collision and eventual merger. After the merger, the newly formed black hole settles into a stable state, emitting gravitational waves as it adjusts to its new configuration. This phase also lasts for a relatively short period.

The collision of two black holes produces gravitational waves—ripples in the fabric of spacetime that propagate outward from the event. These waves were first predicted by Albert Einstein's theory of general relativity in 1916, but it was not until 2015 that they were directly detected by the Laser Interferometer Gravitational-Wave Observatory (LIGO).

This event, known as GW150914, marked the first direct observation of gravitational waves and confirmed a major prediction of general relativity. The black holes involved in this merger were estimated to have masses of about 36 and 29 times the mass of the Sun [13].

However, if vortices with opposite signs attract and translate parallel to each other and are linked by their swirling arms from one side only (**Figure 6**).

Figure 6. A remarkable attraction between two spiral galaxies, NGC 6050 and IC 1179, and is part of the Hercules Galaxy Cluster, located in the constellation of Hercules. This image is from NASA's Hubble Space Telescope. Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration, and K. Noll (STScI).

The same process can take place in the quantum realm. The encounter between quark and antiquark mediated by gluons, binds quarks together within mesons (**Figure 7**).

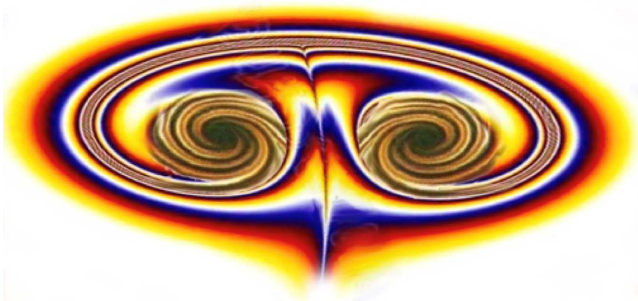

Figure 7. An artistic illustration of a meson structure, showing the connection details between a quark and an antiquark. In the upper part of the illustration, the quark and antiquark are shown being attracted to each other due to their opposite rotation directions. In the lower part, the quarks are depicted experiencing repulsion due to the parallel spiral arms of gluons, this disposition explains the instability of the meson.

The meson unstable structure quark and antiquark spiral arms connection in the upper side and parallel lines without attraction in the lower side. These particles are each other's antiparticles, and they have the tendency to annihilate each other when they come into contact.

These processes ensure that mesons, despite being bound by one of the strongest forces in nature, have finite lifetimes and eventually decay into other particles. The join of the third quark stabilize the structure to give the stable structure of the proton.

7. The Quark Radius

Despite their importance, determining the precise size of a quark remains one of the most challenging and intriguing questions in modern physics. Quarks are point-like particles in the Standard Model of particle physics, meaning they are considered to have no internal structure and no measurable size. However, this point-like description is a theoretical idealization. In practice, understanding the "size" of a quark involves examining how quarks interact with other particles and fields at extremely high energies this is called charge radius.

The concept of charge radius is generally associated with composite particles like protons, which have a charge radius around 0.84×10^{-15} meters [14]-[16].

The radius of a quark in relation to the radius of a proton can be understood by looking at their respective scales.

We can calculate the radius of the meson by applying the strong force interaction between two quarks. According to the equation:

$$F_{\text{strong}} = 3/4\alpha_s \hbar c/r^2$$

- α_s is the strong coupling constant,
- $\hbar$ is the reduced Planck constant ($1.0545718 \times 10^{-34}$ J·s),
- c is the speed of light (2.998×10^{8} m/s),
- r is the distance between the quarks.

The value of α_s is determined experimentally through various high-energy physics experiments, including deep inelastic scattering, jet production in hadron colliders, and the study of quarkonium states. The value of α_s at the scale of the Z boson mass ($M_Z \approx 91.2$ GeV M) is approximately 0.118.

While this is more difficult to define strong force between quarks precisely, we can use a general estimate of the force in the range of 10^3 to 10^4 Newtons based on previous high-energy physics considerations. For simplicity, let's use $F_{\text{strong}} = 10^3$ N.

Substitute the known values into the formula:

$$r = \sqrt{3/4\alpha_s \hbar c / F_{\text{strong}}}$$

$r \approx 1.673 \times 10^{-15}$ m.

However this radius expresses the distance between the two quarks the real radius of the quark should be smaller.

The expected quark radius should be 1/2 of the distance between two quarks, therefore the charge radius of the quark expected to be around 0.836×10^{-15} m which is the same range of the proton radius.

8. Applying Hydrodynamic Principles on the Quark Vortex

The charge radius determines the effective size or charge distribution of a quark inside a hadron. It can be inferred indirectly from high-energy scattering experiments and quantum chromodynamics (QCD) calculations. These interactions are typically interpreted through the form factors of hadrons rather than direct measurements of quark sizes.

Let's first apply the hydrodynamic principle to calculate the distance between the two quarks and then calculate the radius of the quark.

In fluid dynamics, a vortex is a region where the fluid's rotation is concentrated. The strength of the vortex is described by the circulation Γ, which is defined as the line integral of velocity around a closed loop:

$$\Gamma = \oint v \cdot \mathrm{d}l$$

The interaction between two vortices in a fluid can lead to forces that are somewhat analogous to forces between charged particles or masses. However, the exact force law depends on the specifics of the vortex interaction.

In a previous article, we demonstrated that the electron can be modeled as a frictionless vortex with conserved momentum, made out of condensed vacuum. The circulation in the quark vortex is similar to that of the electron and can be expressed as:

$$\Gamma_u = h/m_u = \text{constant} .$$

Given:

- Planck's constant $h = 6.6262 \times 10^{-34}$ J·s
- Mass of the up quark $m_u \approx 2.3 \times 10^{-30}$ kg

$\Gamma_u = h/m_u \approx 2.8792 \times 10^{-4}$ m²·s⁻¹

However, Γ_u is not a simple diffusion-like or circulation interpretation, but rather a more complex quantity incorporating not just spatial and temporal elements but also mass, with a different geometric interpretation. The units of Γ_u are:

$$\Gamma_u = \frac{\text{m}^{5/2} \cdot \text{kg}^{1/2}}{\text{s}^2 \cdot \text{C}}$$

This indicates that Γ_u includes a dependence on charge (C^{-1}, suggesting that electric charge plays a role, potentially in charged particle dynamics. Furthermore, Γ_u could imply a relationship with time-dependent force or acceleration.

The force related to two vortices is directly related to the circulation and inversely related to the sphere surface and to the stiffness of the superfluid vacuum, according to the equation:

$$F_{\text{vortex-like}} = \frac{\Gamma^2}{4\pi r^2 \varepsilon_0}$$

In a previous article [17], we demonstrated that electric permittivity is the expression of stiffness due to the compressibility of the vacuum, which is the capability of the vacuum to permit an electric field. This has the value:

$$\varepsilon_0 = 8.854187817\ldots \times 10^{-12} \text{ F/m.}$$

The value $1/4\pi\epsilon_0 r^2$ corresponds to the known k, which is the electric constant

$$k = 1.6 \times 10^{-19} \text{ N·m}^2$$

The strong force in the proton is estimated to be between 10^3 N and 10^4 N.

- For $F = 10^3$ N, $r \approx 3.64 \times 10^{-15}$ m.
- For $F = 10^4$ N, $r \approx 1.15 \times 10^{-15}$ m

This radius is within the range of the accepted values for the proton radius, which should be bigger than the quark radius.

The radius of a single quark

According to the vortex model, the strong force of the quark corresponds to the centripetal force of the quark vortex. To calculate the charge radius of the quark, considering it as a vortex, we can use the formula that expresses the centripetal force:

$$F = mv^2/R$$

where:

- F is the force = 10^3 N to 10^4 N
- $m_u \approx 3.9218562 \times 10^{-30}$ kg
- $v = c = 3 \times 10^8$ m/s
- R is the radius.

we can calculate the radius R as:

$$R = mv^2/F$$

Substituting the values:

when the force is in the range of 10^3 N

$$R \approx 3.52967058 \times 10^{-16} \text{ m}$$

If the force of the quark in the range of 10^4 N then the radius will be

$$R = 3.52967058 \times 10^{-17} \text{ m}$$

Both values are within the expected ranges.

So The ratio between the distance of the two quarks in the proton or meson and the radius of a single quark is:

$3.52967058 \times 10^{-16}$ $m/r \approx 3.64 \times 10^{-15}$ m is approximately 10.31

This ratio changes as the force increases and the radius decreases, potentially making the ratio significantly larger under stronger forces or smaller radii.

The mass calculation of the quark

By leveraging hemodynamic principles, we can calculate the mass of a quark and validate the vortex nature of its structure.

In a previous article [10], it was demonstrated that the electron's negative charge is associated with an attractive force toward the center of an electron vortex. The force due to the electron's charge is given by:

$$F = e^2/4\pi r^2 \epsilon_0$$

where:

- e is the elementary charge (1.602×10^{-19} C),
- ϵ_0 is the permittivity of free space (8.854×10^{-12} F/m),
- r is the radius in the range of 10^{-15} m,
- c is the speed of light (3×10^8 m/s).

This force is equal to the centrifugal force of the electron vortex:

$$F_c = mc^2/r$$

By equating the attractive force and the electron charge force, we have:

$$e^2/4\pi r^2 \epsilon_0 = mv^2/r$$

We can solve for m by rearranging the equation:

$$M = e^2/4\pi rc^2 \epsilon_0$$

We replace the Quark charge and the radius of the quark and calculate the mass of the up Quark.

$$m_u \approx 1.28 \times 10^{-29} \text{ kg.}$$

The calculated radius and mass of the up quark align with known quark ranges of radius and mass, supporting the notion that quarks can be modeled with a vortex structure. This model enhances our understanding of quark properties and interactions at the quantum level, reinforcing the applicability of hydrodynamic principles to subatomic particles. By considering quarks as possessing such structures, we gain a deeper understanding of their intrinsic properties and interactions at the quantum level.

9. The Volume and the Density of the Quark

The quark structure can be compared to the electron and spiral galaxies, where the radius of the vortex doubles when we stretch the vortex to measure the area. Therefore, the area of the quark vortex can be calculated using the formula

$A = 2\pi r^2$, where the radius is $R \approx 3.52967058 \times 10^{-16}$ m

giving an area of

$$A = 2\pi r^2$$

Given:

$$R = 3.52967058 \times 10^{-16}\ \text{m}$$

Substituting the value of r into the equation:

$$A \approx 7.83 \times 10^{-31}\ \text{m}^2$$

In previous article [18], we proposed that in the vortex model, the thickness of the vortex is 50 times smaller than the radius. Therefore, its thickness is:

$$H = r/50$$

The volume of the quark vortex can then be calculated using the formula

$$V = A \times H,$$

where A is the area of the vortex and H is its thickness.

This gives a volume of:

$$V \approx 5.53 \times 10^{-48}\ \text{m}^3$$

Next, we calculate the density of the quark using the formula:

$$\text{density} = \text{mass/volume}$$

The mass of an up quark is approximately:

$$m_u \approx 2.3\ \text{MeV/c}^2$$

1 MeV/c^2 is approximately 1.783×10^{-30} kg. Therefore:

$$m_u \approx 4.1 \times 10^{-30}\ \text{kg}$$

Now the density can be calculated as follows:

$$\rho = m_u / V$$

$$\rho \approx 7.41 \times 10^{17}\ \text{kg/m}^3$$

This result closely aligns with the expected extreme densities of subatomic particles and is comparable to the density of a proton, which is approximately:

$$\rho \approx 6.74 \times 10^{17}\ \text{kg/m}^3$$

given

The mass of a proton is well-known and is approximately $m_p = 1.6726219 \times 10^{-27}$ kg.

And its volume, assuming a spherical shape, is:

$$V = 4/3\pi r^3 \approx 2.48 \times 10^{-45}\ \text{m}^3$$

The radius of a proton is approximately $r \approx 0.84 \times 10^{-15}$ m.

The small deviation in density could be related to the approximation of the proton's volume, which may not be a perfect sphere.

10. Conclusions

This paper presents a new theoretical framework that reimagines quarks as superfluid vortices within the context of quantum chromodynamics (QCD) and the early universe's conditions. By applying principles from classical fluid dynamics, such as angular momentum conservation, vortex stability, and rotational motion, the model provides a robust explanation of key quark attributes, including their spin, mass, and charge. These characteristics are derived from the dynamics of quarks as quantum vortices in a superfluid vacuum, a concept that aligns with modern theoretical physics.

The formalism and calculations performed within this framework yield results that closely match known experimental data, particularly in the areas of quark radius, mass, and density. This new perspective integrates cosmological events with particle physics, offering a cohesive framework for understanding the formation and properties of quarks. The superfluid vacuum's characteristics, which play a crucial role in particle interactions, highlight the intricate interplay of forces and particles in the subatomic world.

The theory also explores the implications of this vortex model on the stability of quarks within protons and neutrons, and how quark-antiquark pairs (mesons) and three-quark structures (baryons) can be understood as interactions between these vortices. By viewing quarks as stable, localized structures within a superfluid medium, this theory offers new explanations for their mass, charge, and interactions. This perspective not only aligns with existing quantum chromodynamics but also opens new avenues for exploring the deep connections between particle physics and the properties of the vacuum.

Furthermore, this approach elucidates the strong force's role as an interaction between these vortices, mediated by gluons in the quantum fluid. The proposed model provides a compelling framework for understanding the fundamental structure of protons and neutrons, offering a novel conceptualization of the processes that occurred during the Quark Epoch of the Big Bang. This model not only helps to conceptualize the behavior of quarks but also sheds light on the fundamental processes that shaped the Universe as we know it.

In conclusion, the vortex model represents a significant step forward in our understanding of quark structure, providing a robust theoretical basis that challenges conventional views and encourages further exploration into the complex and dynamic world of subatomic particles. The integration of cosmological events with particle physics through this model opens new avenues for research and exploration, offering potential pathways for further theoretical developments and experimental investigations into the nature of quarks and their role in the fabric of the universe. This theory holds promise for resolving many of the longstanding enigmas surrounding the proton, including its mass, internal structure, and charge radius. Moreover, it may provide insights into the proton spin crisis and the behavior of quark-gluon interactions within high-energy environments. In the next paper based on this theory, we will further explore these aspects and delve deeper into the proton's structure, expanding our understanding of this fundamental particle and its significance in the broader context of particle physics and cosmology.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Butto, N. (2020) Electron Shape and Structure: A New Vortex Theory. *Journal of High Energy Physics, Gravitation and Cosmology*, **6**, 340-352. https://doi.org/10.4236/jhepgc.2020.63027

[2] Rauscher, E.A. (1968) Electron Interactions and Quantum Plasma Physics. *Journal of Plasma Physics*, **2**, 517-541. https://doi.org/10.1017/s0022377800004013

[3] Rauscher, E.A. (2004) Dynamic Plasma Excitation Modes of Propagation in the Ionosphere. PA Press.

[4] Iida, K. and Baym, G. (2002) Superfluid Phases of Quark Matter. III. Supercurrents and Vortices. *Physical Review D*, **66**, Article ID: 014015. https://doi.org/10.1103/physrevd.66.014015

[5] Iida, K. and Baym, G. (2003) Magnetic and Rotational Vortices in Superfluid Quark Matter. *Nuclear Physics A*, **718**, 697-699. https://doi.org/10.1016/s0375-9474(03)00892-3

[6] Ruutu, V., Eltsov, V., Gill, A., Kibble, T., Krusius, M., Makhlin, Y., Plaçais, B., Volovik, G. and Xu, W. (1995) Big Bang Simulation in Superfluid 3He-B—Vortex Nucleation in Neutron-Irradiated Superflow. arXiv: cond-mat/9512117.

[7] Hayashi, K. and Shirafuji, T. (1977) Spacetime Structure Explored by Elementary Particles: Microscopic Origin for the Riemann-Cartan Geometry. *Progress of Theoretical Physics*, **57**, 302-317. https://doi.org/10.1143/ptp.57.302

[8] Sinha, K.P., Sivaram, C. and Sudarshan, E.C.G. (1976) Aether as a Superfluid State of Particle-Antiparticle Pairs. *Foundations of Physics*, **6**, 65-70. https://doi.org/10.1007/bf00708664

[9] Vilenkin, A. (1985) Cosmic Strings and Domain Walls. *Physics Reports*, **121**, 263-315. https://doi.org/10.1016/0370-1573(85)90033-x

[10] Butto, N. (2021) A New Theory for the Essence and Nature of Electron Charge. *Journal of High Energy Physics, Gravitation and Cosmology*, **7**, 1190-1201. https://doi.org/10.4236/jhepgc.2021.73070

[11] Butto, N. (2020) A New Theory on Electron Wave-Particle Duality. *Journal of High Energy Physics, Gravitation and Cosmology*, **6**, 567-578. https://doi.org/10.4236/jhepgc.2020.64038

[12] Butto, N. (2021) A New Theory for the Essence and Origin of Electron Spin. *Journal of High Energy Physics, Gravitation and Cosmology*, **7**, 1459-1471. https://doi.org/10.4236/jhepgc.2021.74088

[13] Pretorius, F. and East, W.E. (2018) Black Hole Formation from the Collision of Plane-Fronted Gravitational Waves. *Physical Review D*, **98**, Article ID: 084053. https://doi.org/10.1103/physrevd.98.084053

[14] Antognini, A., Nez, F., Schuhmann, K., Amaro, F.D., Biraben, F., Cardoso, J.M.R., *et al.* (2013) Proton Structure from the Measurement of 2S-2P Transition Frequencies of Muonic Hydrogen. *Science*, **339**, 417-420. https://doi.org/10.1126/science.1230016

[15] Bezginov, N., Valdez, T., Horbatsch, M., Marsman, A., Vutha, A.C. and Hessels, E.A.

(2019) A Measurement of the Atomic Hydrogen Lamb Shift and the Proton Charge Radius. *Science*, **365**, 1007-1012. https://doi.org/10.1126/science.aau7807

[16] Xiong, W., Gasparian, A., Gao, H., Dutta, D., Khandaker, M., Liyanage, N., Pasyuk, E., Peng, C., Bai, X., Ye, L. and Gnanvo, K. (2019) A Small Proton Charge Radius from an Electron-Proton Scattering Experiment. *Nature*, **575**, 147-150.

[17] Butto, N. (2021) Revealing the Essence of Electric Permittivity Constant. *Journal of High Energy Physics, Gravitation and Cosmology*, **7**, 210-217. https://doi.org/10.4236/jhepgc.2021.71011

[18] Butto, N. (2024) Unraveling the Quantum Web: The Vortex Theory of Mass and Matter Formation. *Journal of High Energy Physics, Gravitation and Cosmology*, **10**, 1195-1225. https://doi.org/10.4236/jhepgc.2024.103072