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Quantum Electrodynamics (QED) Driving Longitudinal Scalar Wave (LSW) Descriptions and Their Physics and Mathematical Equations

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Abstract: QED (quantum electrodynamics) is the QFT (quantum field theory) describing the interaction between light and matter. While conventional QED is based on TEM (transverse electromagnetic) waves, there has been increasing interest in the theoretical and experimental exploration of LSW (longitudinal scalar waves) solutions that are often omitted in CED (classical electrodynamics) but may have physical significance in nontrivial vacuum conditions. This paper delves into the theoretical foundation of LSW, their role in QED, and the associated mathematical equations governing their dynamics.

Key words: QED, LSW, scalar fields, Klein-Gordon equation, QFT, Feynman diagrams, scalar bosons, electromagnetic field interaction, quantum mechanics, Fourier transform.

1. Introduction

QED (quantum Electrodynamics) is the relativistic QFT (quantum field theory) describing the interaction of light and matter. Rooted in Maxwell's equations and the principles of quantum mechanics, QED successfully explains photon-electron interactions via Feynman diagrams and perturbative calculations. While mainstream electrodynamics emphasizes transverse waves, LSWs (longitudinal scalar waves), often associated with alternative physics and Tesla-like technologies, remain under-explored within rigorous QED formulations. This proposed article aims to bridge that gap by investigating the mathematical and physical foundations of longitudinal waves in the context of QED.

QED serves as the fundamental theoretical framework for describing electromagnetic interactions at the quantum level. Traditional electrodynamics focuses on TEM (transverse electromagnetic) waves, while the concept of LSW has been a subject of extended theoretical discussions in alternative physics and engineering applications [1-4]. This article delves into the physics and mathematical formulations behind QED's interaction with LSW descriptions, exploring their feasibility, potential applications, and underlying quantum mechanical principles.

2. QED: Theoretical Foundation

The QFT of how charged particles interact with the electromagnetic field is known as quantum electrodynamics, or QED. It provides a mathematical description of all interactions between charged particles as well as between light and matter. Because each of the equations in QED incorporates elements of Albert Einstein's theory of special relativity, it is a relativistic theory. All of atomic physics can be viewed as a test laboratory for the theory since atoms and

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molecules behave predominantly in an electromagnetic manner.

Experiments examining the characteristics of subatomic particles called muons have produced some of the most accurate tests of QED. It has been demonstrated that the magnetic moment of this kind of particle agrees with the theory of nine significant digits. QED is one of the most effective physics theories ever developed because of its high accuracy of agreement.

QED is a QFT that describes how electromagnetic radiation (photons) interacts with matter, particularly charged particles like electrons. The development of QED in the 1920s, pioneered by Paul Dirac, Julian Schwinger, and Richard Feynman, was groundbreaking because it merged the two major pillars of physics at the time: quantum mechanics and special relativity.

QED is an extension of quantum mechanics that incorporates the principles of special relativity. It seeks to explain phenomena such as the interaction of charged particles with electromagnetic fields and provides a framework for understanding how light and matter interact at the quantum level.

The primary focus of QED is the quantization of the electromagnetic field. In this theory, the electromagnetic field is treated as a collection of quantum harmonic oscillators, and the interactions between particles are mediated by the exchange of virtual photons. These photons are not real particles traveling through space but rather the quanta that mediates the forces between charged particles. This interaction is represented mathematically using the concept of Feynman diagrams. See Fig. 1.

Taking Fig. 2 into consideration, in theoretical physics, the Feynman diagram is a pictorial representation of mathematical expressions describing the behavior and interaction of subatomic particles. The scheme is named after American physicist Richard Feynman, who introduced the diagrams in 1948.

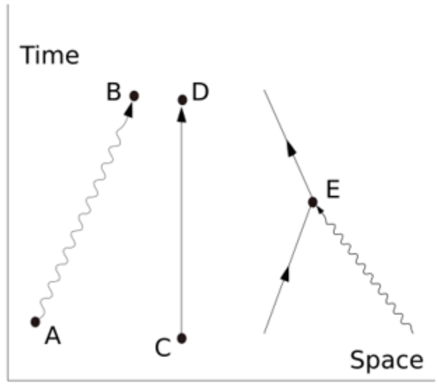

Fig. 1 Feynman diagram elements.
(Source: www.wikipedia.org)

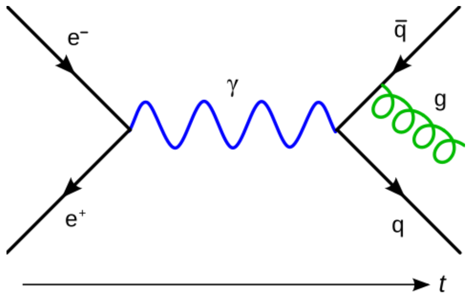

Fig. 2 Feynman diagram.
(Source: www.wikipedia.org)

In Feynman diagram of Fig. 2, an electron (e^-) and a positron (e^+) annihilate, producing a photon (γ, represented by the blue sine wave) that becomes a quark-antiquark pair as quark being q and antiquark shown as $\bar{q}$, after which the antiquark radiates a gluon g, represented by the green helix in this figure.

The core mathematical formulation of QED arises from the Lagrangian density (L) of the electromagnetic field. This Lagrangian density is key to deriving the equations of motion for charged particles and electromagnetic fields. The equation for the four-potential A_μ of the electromagnetic field can be written as [2]:

$$\mathfrak{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{\psi}\left(i\gamma^{\mu}\partial_{\mu} - m\right)\psi$$

where:

$\mathfrak{L}$ is the Lagrangian density of the system,
$F_{\mu\nu}$ is the electromagnetic field strength tensor,
ψ is the Dirac spinor for electron field,
γ^{μ} are the Dirac matrices,

m is the mass of the electron.

This Lagrangian density gives rise to Maxwell's equations in a quantum field framework and explains the interactions of photons with charged particles [5, 6].

3. The Nature of LSWs

The term LSW is a theoretical concept within the context of wave propagation, specifically in fields that exhibit scalar characteristics. Scalar waves differ from the typical electromagnetic waves, where electric and magnetic fields oscillate perpendicularly to the direction of propagation (transverse waves) and also are known as TEM wave, or Hertzian wave [6]. In contrast, longitudinal waves involve oscillations that occur along the direction of propagation itself and have characteristic of energy wave also known as Tesla wave [1, 2].

Scalar waves are described by a scalar field, which means the field is represented by a single value at each point in space and time, as opposed to vector fields, which have both magnitude and direction. A LSW refers to a situation in which the oscillations of the scalar field occur along the direction of the wave's travel. See Fig. 3, where the difference between TEM and LSW is depicted from their motion perspectives [7].

In the classical context of electromagnetism, the electric and magnetic fields in an electromagnetic wave are perpendicular to each other and to the direction of propagation [6]. However, in the case of LSW, the wave's oscillations are parallel to the direction of propagation. Such waves do not exhibit the characteristic transverse nature seen in conventional electromagnetic waves [1, 2].

In quantum theory, the LSW can be seen as a manifestation of interactions mediated by a scalar field. This scalar field can interact with other fields, including the electromagnetic field described by QED. The existence of LSW in QFT raises interesting questions about how these waves might arise and behave in a system governed by the principles of QED [2, 7].

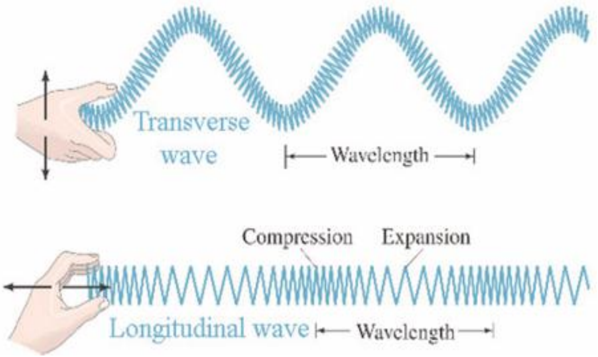

Fig. 3 Illustration of transverse vs. longitudinal waves [7].

4. Hertzian Wave of TEM vs. Tesla Energy Wave of LSW

The difference between Hertzian waves (traditional TEM waves) and Tesla energy waves (often associated with longitudinal or scalar waves) lies in their fundamental propagation modes, physical principles, and theoretical applications.

4.1 Hertzian Wave of TEM Waves

Hertzian waves, named after Heinrich Hertz, refer to classical TEM waves, which are the fundamental solution to Maxwell's equations in free space.

4.1.1 Characteristics

TEM waves have perpendicular electric and magnetic fields propagating at speed of light in free space, following Maxwell's equation with following five holistic rules as:

- Wave Type: TEM—electric ($\vec{E}$) and magnetic ($\vec{B}$) field oscillate perpendicular to each other and the direction of wave propagation.
- Mathematical Form: Governed by Maxwell's wave equations, derived from the second-order differential equation in free space (i.e., vacuum):

$$\begin{cases} \nabla^2 E - \dfrac{1}{c^2}\dfrac{\partial^2 E}{\partial t^2} = 0 \\ \nabla^2 B - \dfrac{1}{c^2}\dfrac{\partial^2 B}{\partial t^2} = 0 \end{cases}$$

- Medium Requirements: Propagate through free space, dielectric media, or conductors.

- Energy Transmission: Classical electromagnetic wave behavior, as used in radio transmission, radar, and communication systems.
- Velocity: Propagate at the speed of light in vacuum (c) and at lower speeds in dielectric media.

4.2 Tesla Energy Wave of LSW

Tesla energy waves, also known as longitudinal waves or scalar waves, are often associated with Nikola Tesla's experimental work on energy transmission and alternative electromagnetic wave theories.

4.2.1 Characteristics

Tesla energy waves are proposed electromagnetic waves with electric field oscillations parallel to the direction of propagation, potentially enabling lossless and superluminal energy transmission. Holistically these characteristics are defined as follows:

- Wave Type: Longitudinal waves—electric ($\vec{E}$) and possibly magnetic ($\vec{B}$) fields oscillate parallel to the direction of propagation, rather than perpendicularly as in TEM waves.
- Mathematical Formulation: Often derived from an alternative interpretation of Maxwell's equations, modifying the wave equation to allow divergence in the electric field:

$$\begin{cases} \nabla \cdot \vec{E} \neq 0 \\ \nabla^2 \Phi - \dfrac{1}{c^2} \dfrac{\partial^2 \Phi}{\partial t^2} = 0 \end{cases}$$

where Φ represents a scalar potential field.

- Propagation Medium: Suggested to propagate through dielectric or vacuum, and possibly through conductive Earth-based transmission.
- Energy Transmission: Proposed to carry energy without attenuation over long distances, differing from classical TEM waves that suffer inverse square law losses.
- Velocity: Some theories propose FTL (faster-than-light) propagation or superluminal group velocities under specific conditions.

In conclusion of the above section, Hertzian TEM waves are well-understood, classical electromagnetic waves used in mainstream physics and engineering. Tesla longitudinal waves remain a subject of experimental and theoretical research, with claims of unique properties such as lossless transmission and superluminal speeds. While TEM waves are widely verified, the existence of Tesla waves in the proposed form requires further scientific validation.

Table 1 Comparison summary of Hertzian versus Tesla energy waves.

Feature	Hertzian TEM waves (classical)	Tesla energy waves (longitudinal/scalar)
Wave type	TEM	LSW
Field orientation	$\vec{E} \perp \vec{B} \perp$ propagation	$\vec{E}$ □ propagation
Maxwell's equations	Derived directly from standard EM field equations	Modified field theory allowing divergence in $\vec{E}$
Medium	Free space, waveguides, conductors	Vacuum, structured media, Tesla coils
Energy loss	Follows inverse square law	Proposed to transmit without loss
Applications	Radio waves, radar, microwave, optics	Wireless power, alternative energy

5. Mathematical Representation of Longitudinal Waves in QED

In the framework of QED, LSW can be analyzed using QFT, where the field is quantized, and particle interactions are mediated by virtual particles. The scalar field $\phi(x)$ can be described by the Klein-Gordon equation, which governs the dynamics of relativistic scalar fields [1, 2].

$$(\Box + m^2)\phi(x) = 0$$

where in the above equation:

- $\Box$ is the d'Alembertian operator, which represents the wave operator in relativistic quantum mechanics.
- m is the mass of the scalar particle.
- $\phi(x)$ is the classical field that represents the longitudinal wave.

This equation describes the propagation of a free scalar field and serves as the foundation for understanding scalar waves in QFT. The solution to this equation describes the evolution of the scalar field as it propagates through space-time.

Scalar fields can also be quantized in a manner similar to the electromagnetic field in QED. In the case of the electromagnetic field, photons are the quanta of the field, whereas in the case of a scalar field, the quanta are often referred to as scalar bosons. These scalar bosons are the fundamental particles that mediate interactions in theories beyond the Standard Model, such as in models of inflationary cosmology.

The interaction between the electromagnetic field and the scalar field is described by the coupling constant *g*, which represents the strength of the interaction between the two fields. The interaction Lagrangian density between the scalar field and the electromagnetic field can be written as:

$$\mathfrak{L} = \mathfrak{g}\phi(x)F_{\mu\nu}F^{\mu\nu}$$

where $\phi(x)$ is the scalar field, and $F_{\mu\nu}$ is the electromagnetic field strength tensor.

6. Propagation and Dynamics of LSW

The propagation of LSW can be described by solving the Klein-Gordon equation under various boundary conditions. For instance, in free space, the solution to the Klein-Gordon equation will describe waves that propagate at the speed of light.

To explore the dynamic behavior of scalar waves, we need to consider the Fourier transform of the scalar field. This allows us to represent the scalar field as a sum of oscillatory components, each with a specific frequency and wave vector. The Fourier transform of the scalar field $\phi(x)$ is given by:

$$\phi(x) = \int \frac{d^3k}{(2\pi)^3}\tilde{\phi}(k)e^{ikx}$$

where:

- $\tilde{\phi}(k)$ is the Fourier transform of the field,
- k is the wave vector, and
- x is the space-time coordinate.

This representation shows how LSW can be decomposed into a superposition of plane waves, with each plane wave contributing to the overall behavior of the field. The dispersion relation for the scalar field is derived from the Klein-Gordon equation and gives the relationship between the frequency ω and the wave vector k:

$$\omega^2 = k^2 + m^2$$

where m is the mass of the scalar particle.

7. Theoretical Implications of LSW

The introduction of LSW into QED opens up several interesting theoretical possibilities. For instance, scalar fields are often associated with fundamental interactions in the early universe. In cosmology, scalar fields are integral to models of inflationary, where rapid expansion in the early universe is driven by a scalar field known as the inflation

The presence of scalar fields could also explain phenomena like dark energy and dark matter, both of which remain mysterious in modern cosmology. Scalar fields could provide a natural explanation for the accelerated expansion of the universe observed in recent cosmological surveys.

Moreover, the concept of LSW has implications for understanding vacuum fluctuations in QFT. These fluctuations arise from the inherent uncertainty in the field, and scalar waves could play a key role in mediating these fluctuations in systems governed by QED.

8. LSW Is True Science: Neither Pseudoscience Nor Fiction

Since its discovery many years ago, scalar energy has mostly been disregarded. Today, scalar energy remains unused, unappreciated, and misunderstood. One must examine the past in order to understand the future. James Clark Maxwell, a Scottish physicist born in 1831, made the initial discovery of scalar energy. Maxwell’s contributions to mathematical physics were noteworthy. He created the theories of radiation and electromagnetic fields. Nikola Tesla developed instruments that proved the existence of scalar energy and expanded Maxwell’s discoveries.

In the early 1900s, Nicola Tesla made the discovery of an electromagnetic longitudinal wave. Wireless energy transfer, lossless power transmission through solid metal objects, and lossless energy transmission over long distances are all possible with it. Tesla did not give it a name or explain how it worked in this patent. It is now known as LSW, or longitudinal scalar waves, in the twenty-first century. The entire field is covered by instantaneous longitudinal waves known as scalars. They do not propagate along an axis or have direction, unlike electromagnetic waves, which are transverse and travel in a specific direction along an axis. As "vector" waves, electromagnetic waves lose power as they travel farther and pass through solid metal objects. Scalar waves also offer a unique property that Tesla does not include in his patent, which concentrates on the transportation of energy. These waves can transmit information as well [8].

9. Applications and Future Research

LSWs driven by QED could have significant implications in various fields of physics and technology. One of the key areas of application is in the study of quantum communication. Scalar waves, if they exist, could potentially provide a new method of communication, allowing for faster and more efficient transmission of information.

In term of communication in form of energetic and wireless signals specifically in deep water conditions, we may tab idea of generalization of CED (classical electrodynamics) to admit a scalar field and longitudinal waves [13].

In concept of such an innovative approach, it is possible to describe CED in the form of two bi-quaternion equations as derived in Ref. [13]. This form is very useful in order to generalize electrodynamics. Generalizing the Maxwell's equation by introducing an extra scalar field is comparable with Maxwell's introduction of the displacement current that allowed for the derivation of the homogeneous field wave equations. This theory predicts the existence of LES (longitudinal electro-scalar) waves in vacuum. Such a wave might be used to transmit and receive signals. The power density vector of such LES waves is energetic, and thus wireless signals might be transmittable in this form and received at a far distance.

It should be noted that because Maxwell's equations are typically invariant with regard to gauge conditions, the theory of electrodynamics can be expressed in biquaternion form. For example, the possible Lorenz inhomogeneous wave equations are obtained from the Lorentz gauge condition. The generalized Maxwell theory, written in terms of the potentials, can automatically satisfy the Lorenz inhomogeneous wave equations without the need for a gauge requirement if a scalar field is introduced into the Maxwell equations [13].

With regard to the transformation of the potentials, this theory of electrodynamics is no longer gauge invariant; rather, it is electrodynamics with broken gauge symmetry. A generalized Lorentz force expression with an additional scalar term; generalized energy and momentum theorems, with an additional power flow term associated with LES waves; the prediction of a LES wave in vacuum; superluminal wave solutions and possibly classical theory about photon tunneling are some of the consequences of the appearance of the extra scalar field terms, which can be characterized as a conditional current regauge that does not violate the conservation of charge [13].

In the case of medical applications driven by LSW, however there are a few speculative areas where LSWs might find indirect or theoretical applications in medicine, though these are still very much in the realm of exploration and not yet practical and few holistic applications which could be worth mentioning are [14, 15]:

(1) non-invasive diagnostic imaging.

(2) targeted therapeutic applications.

(3) biofield interactions and healing.

(4) electromagnetic field therapy.

Although the direct medical applications of LSWs remain speculative and largely unproven, the growing interest in the interaction between quantum fields and biological systems may pave the way for new avenues of research. More experimental data would be necessary to establish any practical use of LSW in medical fields. As it stands, most medical applications of scalar-like fields are more focused on established electromagnetic or bioelectromagnetic technologies, with LSW still very much a theoretical area of study in physics [14, 15].

However, it is worth discussing how LSW, as a theoretical idea, might hypothetically intersect with existing research on autism treatments, particularly in the context of electromagnetic therapies, biofields, and other energetic healing modalities that are occasionally explored in alternative medicine for various neurological or behavioral disorders, including autism.

If the theoretical properties of LSW were ever validated and understood in greater depth, it is possible that they could, in the future, be explored for applications in neurology or psychiatry, including for conditions like autism.

The current, evidence-based treatments for ASD (autism spectrum disorder) typically focus on behavioral interventions, educational support, and sometimes pharmacological treatments to address symptoms. Approaches like ABA (applied behavior analysis), speech therapy, occupational therapy, and sensory integration therapy are the primary methods used to improve social, communicative, and cognitive skills in individuals with autism.

Additionally, neurostimulation techniques like TMS (transcranial magnetic stimulation) and tDCS (transcranial direct current stimulation) are being researched as potential treatments for various neurological and psychiatric conditions, including autism. These are real, scientifically validated technologies based on electromagnetic fields, although their use for autism is still in early stages of research [16].

However, as of now, there is no scientific evidence linking LSW with any direct therapeutic effect on autism. Theoretical concepts like scalar waves are far from being practical medical tools, and there are no clinical studies supporting their use in autism treatment. More research is needed to understand any potential biological effects of scalar waves, let alone their possible impact on conditions such as autism.

In case of defense application, while LSWs are a theoretical construct in QFT, there is no current scientific basis (i.e., at least not in public domain or open literature) or practical application that links them to defense technologies, especially in the context of countermeasures against hypervelocity objects. The speculation around scalar waves in the defense sector is not supported by empirical research, and any potential applications remain purely hypothetical [17, 18].

Modern defense strategies in public domain for countering hypervelocity objects are focused on kinetic interceptors, directed energy weapons (like lasers and high-powered microwaves), and advanced sensor and tracking systems. These technologies are grounded in well-established physics and engineering principles, and research continues to improve their capabilities. Scalar waves, in contrast, lack any current experimental validation that would make them suitable for any defense-related application [19].

In addition, the study of scalar fields and their interactions with electromagnetic fields could lead to new technologies in areas such as quantum computing, where the manipulation of quantum states plays a central role [2].

Further research into the behavior of LSW could reveal new insights into the foundations of quantum mechanics and the nature of space-time itself. By extending the principles of QED into this new realm, scientists may uncover entirely new aspects of particle physics and cosmology.

10. Experimental and Theoretical Implications

While direct experimental evidence of longitudinal electromagnetic waves in a pure vacuum remains elusive, several domains offer potential insights:

(1) Plasma Waves: Observations of longitudinal waves in plasma provide indirect support for their existence in structured vacuum.

(2) Nonlinear Optical Effects: Nonlinear electrodynamics suggests that strong-field environments could host such modes.

(3) Casimir and Vacuum Effects: Casimir forces and vacuum polarization hint at longitudinal fluctuations beyond classical expectations.

Briefly speaking, QED provides a robust theoretical framework for electromagnetic interactions, traditionally described through transverse wave propagation. However, LSW may emerge under specific conditions, including strong fields, nonlinearities, and vacuum effects. The mathematical foundation, ranging from modified Maxwell's equations to effective QED actions, suggests that further exploration into experimental verification is warranted.

11. Potential Applications of AI and ML in the Study and Future Use of LSW

Currently, LSWs are purely theoretical and lack practical applications or empirical evidence. However, if LSW were to be validated in the future, AI (artificial intelligence) and ML (machine learning) could potentially play a role in their study and application. AI and ML could aid in modeling and simulation of scalar fields, optimize control systems for hypothetical LSW-based technologies, and improve signal processing for detecting scalar waves. Additionally, AI could assist in generating new theoretical hypotheses about LSW properties and help automate research in the field. Though there is no current direct use of AI/ML with LSW, these technologies could accelerate progress in understanding and applying scalar waves if their properties are confirmed [20].

12. Conclusion

QED provides the foundation for understanding the interaction of electromagnetic fields and matter at quantum scales. The concept of LSWs, while not traditionally part of QED, offers an intriguing extension of this theory, opening up new possibilities in both fundamental physics and applied science. Through rigorous mathematical formulations and theoretical analysis, LSWs provide a bridge between quantum mechanics, relativity, and the electromagnetic field, allowing for new insights into the fabric of the universe. As research continues, the exploration of these phenomena promises to yield exciting new discoveries in the world of QFT and beyond [9-12].

However, according to Monstein and Wesley [3], scalar electrodynamic waves had to exist in order to derive from Maxwell's equations. In order to determine whether an oscillating electric field has a longitudinal component, they built a mechanical polarizer and assessed how well it could influence signal absorption. They found that when the polarizing rods were parallel to the direction of propagation, the signal was effectively suppressed; when they were perpendicular, the signal was essentially unaffected.

They examined its compliance with the inverse-square law and the law of reflection to determine whether this longitudinally propagated component constitutes a wave. The former bill made a strong case, whereas the latter appears promising but needs experimental improvements [3, 4].

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