Century Old Questions in Physics

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Abstract

Two major theories in physics, relativity and quantum mechanics, have been around for more than a century. Nonetheless, some fundamental questions remain unclear. The nature of reality in quantum mechanics has long been a question as old as the theory itself. Similarly, the effects of special relativity serve as another long-standing issue of how time and space are intertwined. Although the so-called paradoxes arising from special relativity seem to be resolved through a careful interpretation of the theory, it is still intuitively difficult to acknowledge that such effects can occur in our daily lives. Once again, these fundamental questions in physics are reviewed comprehensively with ontological interpretations of principles and laws in physics with the 4-D complex space model.

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Introduction

Special relativity states that, in a moving frame, time elapses more slowly relative to the observer's frame—known as the time dilation effect—and an object's length appears contracted compared to its measurement at rest, referred to as the length contraction effect. However, the physical interpretation of these relativistic effects is indeed counterintuitive. Given that these effects can be derived from the postulate that the speed of light is constant across all inertial frames, fundamental questions arise: Why is the speed of light invariant despite an observer's relative motion, unlike other natural wave motions? Ultimately, how is such a mechanism even possible, and what justifies defining time and space in physics with relation to this light, generalizing it for all physical phenomena?

In the Michelson-Morley experiment, conducted in 1887, the researchers were looking for the luminiferous—a hypothetical medium for the propagation of light waves, similar to other wave motions in natural phenomena—with the expectation of finding an interference pattern in the measurements due to the directional changes of light speed (1; 2). No interference pattern was found, this null result meant that there is no aether or medium for light wave.

Since then, we still have not had a tangible explanation for how light energy propagates without a medium. Many scientists seem to treat spacetime geometry in relativity and the constancy of the speed of light in a vacuum as independent assumptions, which leads to the view that the fixed speed of light arises from the structure of spacetime itself. In modern physics, however, the constancy of the speed of light is typically attributed to the properties of fields, which are taken as ontological primitives.

On the other hand, when we say that light has wave-particle duality, we don't mean that light is literally both a wave and a particle as fixed identities. Rather, we mean that light exhibits wave-like and particle-like properties, depending on how it is observed and measured. In macroscopic phenomena, we typically observe the wave behavior of light. In contrast, at microscopic scales—such as the atomic or nuclear level—the particle-like behavior becomes evident. The interpretation of the wave function in quantum mechanics—a more than 100-year-old question—is still under debate regarding whether it possesses physical reality. (3; 4)

Regarding ontological reality, the invariance of the speed of light in special relativity and the wave-particle duality of light remain cornerstone issues in modern physics. These fundamental questions, however, have yet to be definitively resolved, at least from an ontological perspective. If the natural phenomena used to validate physical reality are not self-contained, it follows that there may be irrational phenomena that transcend our conventional reasoning.

It is often said that scientists ought not to ask why, but rather how, which is agreeable in general; however, it is not always right. For example, fields in physics—such as gravitational and electromagnetic fields—are physical quantities, each of which is presumed to have an ontological reality. Usually, their nature is not questioned; instead, their roles in physical phenomena are explained. However, if there is a common ontological basis for gravitational and electromagnetic fields; it would provide a more profound, unified understanding of these physical phenomena.

Ontological Foundation in Physics

Physical Vacuum

As an ontological reality in physics the 4-D complex space was introduced (5), with which we could open a new paradigm to understand natural phenomena. First, the physical vacuum was defined in imaginary subspace composed of negative energy-positrons (**vacuum particles**), implying that these particles are confined within this subspace. The second, the first principle of 4-D complex space was postulated as follows: vacuum particles in the imaginary subspace spontaneously rearrange themselves in the presence of physical objects in the real subspace to reach an equilibrium of net charge density and net mass density in 4-D complex space. Furthermore, their spins realign in response to any dynamic state of electric charges in the real subspace (**physical space**) to minimize the dynamic variation within the space (6). Consequently, physical interactions—in which positive mass and energy manifest as physical realities—are seen as real projections of interacting vacuum particles in the imaginary subspace (**vacuum space**), rearranged in the presence of physical objects.

With the first principle postulated in the 4-D complex space, we can review ontological foundations of laws and principles in physics, not quantitatively but consistently and comprehensively under one umbrella that is ontological reality of physical interactions.

For the fundamental interactions in physics such as electromagnetic and gravitational interactions, not only can we understand why and how these physical interactions originate in vacuum space, but we can also figure out why gravity is such weak to electromagnetic interaction considering of vacuum particle's charge ratio to its mass. However, the other interactions known as weak and strong interactions are considered as special cases of electromagnetism. (7; 8)

Momentum and Kinetic energy

The momentum and kinetic energy of a moving object in physical space are interpreted as being possessed by the wave motion of vacuum particles generated by the moving object. In contrast, potential energy—defined as the energy stored in a field, such as a gravitational field—can be understood as a result of the tension in the distribution of vacuum particles due to gravitational interactions.

In Figure 1, a physical object with mass m moves through physical space, while the wave motion of vacuum particles—interpreted as the object's kinetic energy—follows in vacuum space. Correspondingly, the energy of the object is expressed via the Pythagorean theorem in Euclidean geometry, which is consistent with special relativity and comparable to the $U(1)$ gauge symmetry in classical electromagnetism and Quantum Electrodynamics (QED).

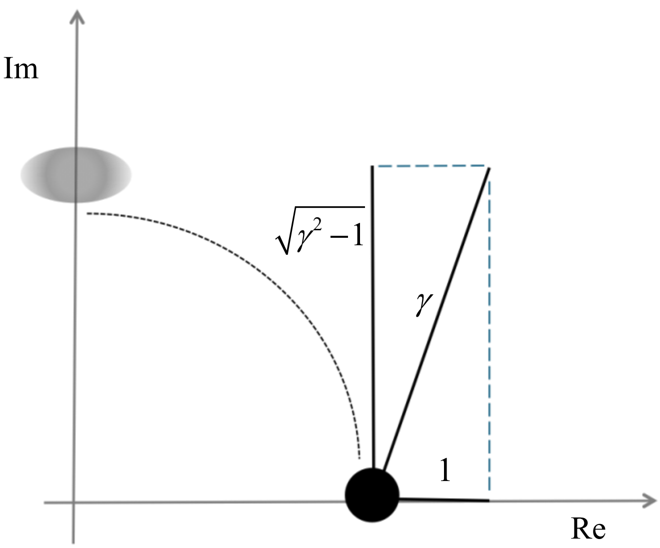

Figure 1: A massive object moves along the real axis, while its kinetic energy evolves along the imaginary axis.

In Figure 1, the object's rest mass energy is represented on the real axis, while its kinetic energy is represented on the imaginary axis in units of its rest mass energy (m_0c^2). Here, γ is the Lorentz factor, defined as $\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$. Consequently, the energy of an object moving with velocity v is expressed as $E = m_0c^2\sqrt{1+\left(\gamma^2-1\right)}$ (as shown in Figure 1), where kinetic energy of the object $K = m_0c^2\sqrt{\gamma^2-1}$. Considering the momentum of the object p is expressed as $p = m_0\gamma v$; thus, $pc = m_0c^2\sqrt{\gamma^2-1}$, it is consistent with the energy expression in special relativity as $E = \sqrt{m_0^2c^4+p^2c^2}$.

Inertia

The inertia in Newton's law is interpreted as the reaction of vacuum particles to the imbalanced tension exerted by an external force on a massive object. Since gravitational force stems from the tension of vacuum particle distributions with imbalanced net mass density in the space, the equality of inertial and gravitational mass—an empirical fact that forms the foundation of general relativity—becomes understandable from an ontological perspective.

Entropy
One of core concepts in physics, entropy, which is defined as measure of disorder in a thermodynamic system, can be reviewed as following: if the measure of disorder is considered not only for a physical object but also with vacuum particles holding the object with the first principle given in 4-D complex space, it can be natural to understand the laws of thermodynamics.

The distribution of vacuum particles for a physical object arises from their spontaneous reaction with the first principle in 4-D complex space. This implies that the distribution exists in an equilibrium state—the most probable state for that object. Consequently, not only do we understand the laws of thermodynamics, but we also gain clues as to why entropy in natural phenomena is irreversible and why absolute zero temperature cannot be reached.

Furthermore, using our earlier interpretation of an object's kinetic and potential energy in a gravitational field, we can illustrate the concept of entropy. Let's say there are many massive objects scattered in space; they all attract one another under gravity and merge into a single body. In this process, the entropy of the system apparently decreases, but some energy loss is indispensable. That is, entropy can be reduced through mechanical work, but there must be an accompanying loss of energy.

Primitive Virtual Negative Charge
According to the first principle postulated in 4-D complex space, we can understand fundamental interactions—such as electromagnetic and gravitational forces—and infer the interaction between physical mass and electric charge. The strength of this mass-charge interaction was estimated using a primitive virtual negative (PVN) charge defined for physical mass. From this, we found the PVN charge dynamo mechanism to explain how the geomagnetic field of Earth, as well as the magnetic fields of other planets and stellar objects in general, could be generated (6; 9; 10). Although the scientific consensus holds that the initial generation of the geomagnetic field and its subsequent polarity reversals are entirely self-sustaining processes that do not involve any external interactions, this view may eventually be challenged.

Relativity

In theory of special relativity, the speed of light is postulated as constant in all inertial reference frames. Even though light is known as electromagnetic wave, it has no medium for the wave motion not as other kinds of wave motions in natural phenomena. The reason that light is such special can be explained as following: in 4-D complex space, the wave motion of light is interpreted as the wave motion of vacuum-particle-string in vacuum space (imaginary subspace), which is orthogonal to physical space (real subspace); hence the speed of light is independent of the relative motions between two inertial frames of reference in physical space. (5)

Considering that the effects of special relativity, such as time dilation and length contraction, emerge when observing light signals in two inertial frames moving relative to each other, it can be confidently stated that special relativity is valid, at least, for natural phenomena involving electromagnetic interactions between these frames. Special relativity applies to both frames, where the spacetime 4-vector, energy-momentum 4-vector, and the 4-vectors in electromagnetism are conserved under Lorentz transformations.

On the other hand, the gravitational redshift in general relativity is interpreted as the variation in the wavelength of light under a gravitational field, generated by vacuum particles arranged in the presence of a massive object in physical space. Its equivalence to the effects of special relativity is illustrated through a thought experiment comparing the effects of special relativity in inertial frames that are momentarily co-moving within a gravitational field (11). Thus, this interpretation leads to the conclusion that the effects of special relativity apply to vacuum particles that intrinsically participate in physical interactions.

Space and Time in Special Relativity

The principle of special relativity states that all inertial frames of reference are equivalent, meaning that the laws of physics are the same for all non-accelerating (inertial) frames. In other words, natural phenomena can be explained in any inertial frame using the same principles and laws of physics. Additionally, the theory assumes that the speed of light is constant in all inertial frames, indicating that space and time in these frames are no longer independent of each other.

As a good example, we can explain muon decay, in which the muon's lifetime is known to be 2.2 microseconds (μs). Muons are created in the upper atmosphere when cosmic rays interact with atmospheric particles. Although the lifetime of a muon is 2.2 μs in its own rest frame, it can survive and reach the Earth's surface, traveling much farther than the distance covered in 2.2 μs, even at the speed of light. In the muon's frame, the distance to the Earth's surface is contracted by the Lorentz factor γ due to length contraction in special relativity, while in the frame of the Earth's surface at sea level, time dilation occurs with the same γ factor arising from time dilation in special relativity. Consequently, this phenomenon can be explained in both frames of reference as in the principle of special relativity. In addition, considering of space-time 4-vector conservation, we need to see the length contraction and time dilation effects in special relativity are not independent of each other.

Now, we can review other examples of so-called paradoxes, such as the ladder paradox and the twin paradox. Although these paradoxes are resolved by addressing the relativity of simultaneity in special relativity (12), they are not only hard to understand intuitively, but there is also reason to investigate them further.

Let’s review the muon decay process as above, but now consider two muons: one at the center of Frame A and the other at the center of Frame B. These two inertial frames of reference move relative to each other at a constant speed, v, close to the speed of light. To be realistic, let’s say Frame A is at sea level with Observer A, while Frame B is at the top of the atmosphere with Observer B. At a specific moment, both muons begin the decay process. To Observer A, the muon in Frame B (Muon B) is descending at speed v; Observer A confirms that Muon B survives long enough to reach the center of Frame A. By the same token of reciprocity, to Observer B, the muon in Frame A (Muon A) is ascending at speed v, and Observer B confirms that Muon A survives until it reaches the center of Frame B.

A fundamental question arises regarding physical reality. Considering the time dilation effect in special relativity, Observer A can meet Observer B and Muon B at the end of its decay process, even though A's own stationary Muon A has already decayed. Conversely, Observer B can reach Observer A while Muon A is still present, even though B's own stationary Muon B is gone.

This leads to a paradox: while the two observers can meet, the two muons never do. Observer A sees Muon B survive, but Observer B does not, as it has already decayed in B's own frame. Likewise, Observer B sees Muon A survive, while Observer A does not, as it has already vanished. This is not merely a matter of simultaneity; it is a question of physical reality (conceding its existence in empiricism) versus the contradictions within scientific rationalism that arise from symmetry and reciprocity. To resolve this paradox, we must recognize that the time dilation in special relativity does not literally 'happen' to spacetime itself, but its effect emerges in natural phenomena. To put it simply, time dilation in a moving frame does not alter the nature of time, but rather causes the physical processes within that system to slow down.

Since relativistic effects are fundamentally interdependent, length contraction should be viewed in the same light. For instance, if two identical rulers move toward each other, the theory dictates that each observer will perceive the other's ruler as shorter than their own. This manifestation of length contraction challenged classical intuition over a century ago and has remained a subject of conceptual debate, particularly among dissident scientists. It is analogous to the 'wavicle'—a synthesis of wave and particle—which compels us to accept that light possesses mutually exclusive properties when viewed through an empirical lens. Overall, we must conclude that relativistic effects—such as time dilation and length contraction—are not 'literal' physical changes to an object, but rather manifest as phenomena inherent to the act of observation within a relativistic framework.

When measuring time and space coordinates using light signals across two different inertial frames, the time and space coordinates are not independent. This is because the speed of light in free space is invariant, remaining constant regardless of the frames' relative motion, which necessitates the effects of time dilation and length contraction. In contrast, if a different signal—such as sound—is used to measure them, the time and space coordinates remain independent parameters, as they do in classical physics. Because the speed of sound is not invariant and varies based on the observer's relative velocity, it does not require the coordinate mixing found in relativity. Ultimately, the effects of special relativity emerge specifically from the unique constraints required to maintain a constant speed of light across all frames of reference.

According to the interpretation of light in 4-D complex space, the wavelength of light is related to the number density of vacuum particles, and this number density is rearranged in the presence of a massive object, in accordance with the first principle posited in 4-D complex space. Additionally, physical interactions originate from vacuum particle distributions and their interactions in vacuum space. Considering that gravitational redshift is characterized by the wavelength of light becoming longer as it moves away from a gravitational center, it can be interpreted as follows: the rearrangement of vacuum particles leads to gravitational redshift. Moreover, the effects of special relativity arise from vacuum particle distributions in vacuum space, both within a gravitational field and between two inertial frames of reference, where these effects are realized through interactions between the two frames.

Given that the relationship between space and time in physics depends on light signals, special relativity is inherently linked to electromagnetic interactions involving light signals or photons. Since atomic clocks operate using the resonant frequency of atoms—determined through electromagnetic interactions—it is natural to expect a time dilation effect in atomic clocks influenced by gravity.

However, an intriguing question arises regarding how closely muon decay, which is a weak interaction—not an electromagnetic one—neutrinos, not photons, play a role, can be explained in a manner consistent with the expectations of special relativity. Since neutrinos are also regarded as wave motion of vacuum particles (13; 14), similar to how light behaves in vacuum space that is orthogonal to physical space, the speed of neutrinos should be constant in all inertial frames of reference, just as it is for light. If muon decay can be accurately explained using special relativity, the speed of the neutrino should match that of light. This would suggest that special relativity is valid for physical interactions in general, assuming its validity extends to gravitational and strong interactions.

In fact, there is no imperative reasoning that time and space coordinates—or simply spacetime in physics—are unique and necessarily intertwined with light. Therefore, the effects of length contraction and time dilation in special relativity can be observed using light signals; however, they must be distinguished from physical reality. Consequently, we need to clearly understand what the time dilation effect in special relativity is: time does not change by itself; rather, physical processes are slowed down. Interestingly, if the biological processes in a body are connected to electromagnetism, the aging process is slowed down under the influence of gravity. The body can live longer in the presence of gravity than in a gravity-free environment; however, this is similar to the way food is preserved in a freezer.

Quantum mechanics

Besides the constancy of the speed of light in inertial reference frames, there is the wave-particle duality of light. Light shows both properties in different experiments, though these properties are mutually exclusive and never observed simultaneously. Ironically, the energy of a photon in its particle-like expression is expressed using wave properties—wavelength and frequency—and physical constants such as Planck’s constant and the speed of light.

Given our interpretation of light as the wave motion of vacuum-particle-strings in vacuum space, we need to account for the photon's particle-like behavior observed in subatomic and atomic scale phenomena. For example, in the electromagnetic interaction underlying the photoelectric effect, if incident light has a frequency greater than a certain threshold, electrons are ejected from the surface of the metal plate in which they have been confined. However, the ejection of electrons occurs almost instantaneously, and kinetic energy of the ejected electrons does not depend on the light intensity. Interestingly, we can find a similar case in classical physics that depends on wave properties not its intensity in sound wave resonance in a closed-end tube.

The explanation is as follows: when a light wave—modeled as a vacuum-particle-string in vacuum space—passes a bound electron over the distance of one wavelength, it is determined whether an interaction occurs. Due to the selectivity of a single vacuum-particle-string and the brief interval required for light to travel one wavelength, the photon's energy is interpreted as the energy contained within that single wavelength of the wave. This can be illustrated in the drawing shown in Figure 2, where the photons must pass through the gorge one by one; moreover, only the strong ones can overcome the guard blocking them in the gorge (15).

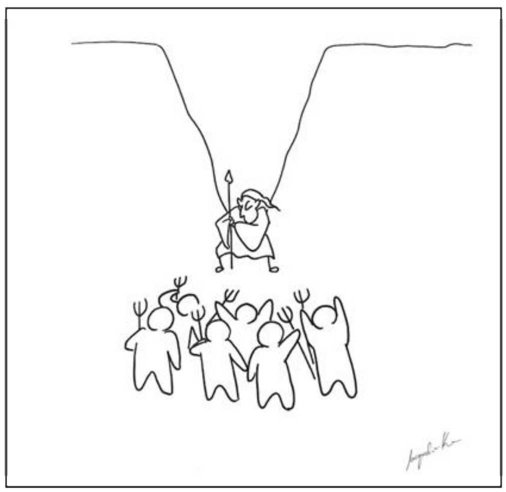

Figure 2: Gorge

In 4-D complex space, the wave function in quantum mechanics is the representation of vacuum particles within vacuum space. These particles rearrange in response to a physical object—in accordance with the first principle postulated in 4-D complex space—and their distribution follows the physical object in a wave-like form. In other words, the wave function is interpreted as a mathematical representation of an essential property—the inherent statistical nature—of natural phenomena.

Consequently, it is linked to the ontological reality of vacuum particles that participate in physical interactions. Hence, uncertainties in physical quantities such as position, momentum, and energy necessarily arise, implying the absence of locality as defined in classical physics. On the other hand, wave function interference is also expected, as the wave-like nature of the function pertains not to the physical object itself, but to the vacuum particles alongside it.

Now, let's consider the physical reality of the wave function. In the double-slit experiment, the interference pattern produced by a single particle—such as a photon, an electron, or even a larger molecule—defies classical intuition and leaves us puzzled. This leads to the question: what if the particle passes through both slits simultaneously? Such a scenario implies that a particle can exist in multiple places at once; consequently, if this process is modeled using wave functions, the wave function component at each slit could be interpreted as a distinct physical reality.

As mentioned previously, the kinetic energy of a physical object is carried by the wave motion of vacuum particles moving alongside it; in fact, these particles inherently participate in physical interactions. It doesn't matter which slit a particle passes through because its wave-like behavior stems from the wave motion of vacuum particles transporting its kinetic energy. Consequently, it is unnecessary to hypothesize that the particle passes through both slits simultaneously to produce an interference pattern, which means that many worlds interpretation (MWI) of wave function in quantum mechanics (16; 17; 18; 19) seems to be gone too far because the motivation itself for the MWI is not valid.

All natural phenomena exhibit both particle-like and wave-like properties. However, the particle-like property becomes prominent in macroscopic phenomena when the kinetic energy of an object is much smaller than its mass energy, whereas the wave-like property dominates when the kinetic energy is significantly higher than the mass energy.

Quantum Entanglement

Since the wave function is interpreted as representing vacuum particles alongside physical objects, the study of quantum entanglement shifts from questions of reality or locality to how multiple quantum states interfere instantaneously across a distance.

This discussion involves conservation principles in physics, such as momentum and energy, as well as the spin or magnetic moment of elementary particles. For example, consider two electrons created in a singlet state: one spin up and the other spin down. When the spin of one electron is measured, the act of measurement affects its spin state (causing its quantum state to collapse); almost simultaneously, the spin state of the other electron is also affected to maintain the singlet state. In describing these spin states, the bonding of two electrons in a singlet state—a physical interaction related to their spins—can be viewed as originating from their creation, given that electron spin behaves like a minute magnet. Remarkably, this bonding can be maintained over considerable distances, as demonstrated in many experiments; this is a crucial aspect of quantum entanglement that requires a physical explanation. To account for this, a new mechanism of physical interaction—the subtle-spin-string wave—has been proposed. (20)

Multiverse Idea

Throughout human history, the belief in worlds beyond our own has been prevalent across various religions, cultural traditions, and ancient philosophies. However, such beliefs remain purely metaphysical and exist outside the scientific realm, as there is no empirical evidence or objective data to support them. Conversely, the concept of "other worlds" has also been suggested in physics. One example is the Many-Worlds Interpretation (MWI)—although it is highly speculative—and similar multiverse concepts have emerged in cosmological theories as well. While there are various theoretical motivations for these ideas, the MWI and multiverse theories currently remain in the metaphysical realm, as they lack empirical evidence or any foreseeable clues for future verification.

However, geological history shows that the geomagnetic field has flipped many times, approximately every 450,000 years on average although the timing varies significantly (21). In the PVN charge dynamo mechanism, a reversal of the geomagnetic field is possible only if the temperature of the Earth's interior is increased (22). The possible energy source is hypothesized to be neutrinos–especially high-energy neutrinos–and the flux of such neutrinos would need to remain high and persist for some time to trigger a nuclear fission process inside the Earth.

Realistically, it is difficult to imagine such a high-energy and persistent neutrino flux existing in our solar system, our galaxy, or even the known universe. While this seems improbable, we might consider the multiverse as a potential source for the neutrino flux required to drive a geomagnetic field reversal.

The cosmological multiverse may be real, moving beyond the metaphysical realm. A potential clue—or evidence that may yet emerge—arose during efforts to understand Earth's geomagnetic field, specifically how it is generated and why it has reversed throughout geological history. In this context, the multiverse is posited as a collection of numerous, rather than infinite, observable universes, based on the premise that an unobservable universe holds no physical relevance. Under this theory, the multiverse's existence would be evidenced by a significant increase in high-energy neutrino flux and a corresponding rise in Earth's interior temperature.

Discussion

In the ontological reality introduced in physics, the philosophical attitude is objectivism regarding natural phenomena, which means that the truth in natural science exists independently of human existence. When we refer to space, it should be considered an abstract background for describing physical phenomena, not as a physical reality itself. In general relativity, however, gravity is understood as a geometric curvature of spacetime affected by mass-energy, suggesting that spacetime possesses an ontological reality. It should be noted that any ambiguity regarding this ontological foundation could limit further theoretical development.

The many-worlds interpretation (MWI) arose with the belief that the wave function in quantum mechanics is objectively real, or at least it has an ontological reality, saying that all quantum states are real and never disappear with the process of wave function collapse, instead, they appear in branching other worlds, which is many-worlds theory. Here, the belief of the ontological reality is vague, which doesn't have a clear picture of what it is.

In 4-D complex space, space is merely an abstract background held with timeless and endless. In real subspace, natural phenomena are real projections of interacting vacuum particles, which are confined to the imaginary subspace (vacuum space), possessing negative mass and energy, and intrinsically participating in physical interactions. On the other hand, the spacetime in general relativity is regarded as a physical state, exactly–ontological reality–woven with geometries formed in the presence of mass-energy. From an ontological perspective, we can compare which framework is more comprehensive than the other.

Physical interactions in the 4-D complex space originate from vacuum particles interacting in the vacuum space. The effects of special relativity are associated with the distribution of these particles; hence, the relativistic effects observed in general relativity are interpreted as the result of vacuum particle distribution under the influence of gravity. On the other hand, in general relativity, the spacetime geometry in the presence of mass-energy—the weaving together of space and time—is fundamentally embedded with the physical effects of vacuum particle distributions.

As previously noted, the effects of special relativity—such as time dilation and length contraction—can be demonstrated by observing light signals across two inertial frames. This confirms that special relativity holds true for natural phenomena involving electromagnetic interactions. Although it has been extensively validated, the theory's universal applicability remains uncertain; furthermore, its intended scope is not explicitly defined. It does not matter whether light is present; nature exists independently, as do the laws of physics.

In 1905, Einstein's theory of special relativity was published under the title "On the Electrodynamics of Moving Bodies" (23). In 1916, he followed with his theory of general relativity, which interprets gravity as the curvature of spacetime influenced by mass-energy. Until that point, electromagnetic interactions were likely a major concern in physics. Since neutrinos were discovered in 1956, we have come to understand that physical interactions are mediated by bosons–such as $W^{\pm}$ and Z^{0} in weak interactions, photons in electromagnetic interactions, hypothesized gravitons in gravity–which indicates that light is not the only entity involved in physical interactions.

If gravitons and neutrinos are assumed to be massless, their speeds should be invariant across all inertial frames of reference—given that vacuum space is orthogonal to physical space in 4-D complex space, just like the speed of light. If the applicability of special relativity is shown without a doubt in gravitational and weak interactions, confirming the theory is truly universal, we can infer that the speeds of gravitons and neutrinos are identical to the speed of light (c). This, in turn, reinforces the premise that these particles are massless.

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