Is the Speed of Light c of Dual Nature?

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Abstract: The wave-particle duality of light is a well-established concept of modern physics. It postulates that light exhibits both a *wave-like face* and a *particle-like face*. But this *Janus*-faced concept was never consciously applied to the speed of light itself. If light has two faces, it would be naturally to assume, that the speed of light has two faces as well. This assumption which I am calling the »Dual Parametrization of c« shall be outlined.

1 Introduction

The speed of light, usually denoted by the symbol c, is one of the fundamental constants of Nature. It is intimately connected with a specific symmetry, which is called *Lorentz invariance*. This symmetry requires that all fundamental laws of physics have to be invariant under Lorentz transformations. Most of our fundamental theories, like quantum electrodynamics, quantum chromodynamics, the Standard Model of particle physics, and general relativity are expressed in a lorentzinvariant fashion.
Hence, our physical understanding of the fundamental constant c determines essentially how we look at the universe.
In modern physics this understanding is mediated by Einstein's Special Theory of Relativity. Though this theory is as far as its experimental basis is concerned highly successful, it has been attacked as false and misleading again and again – until today. One of the main reasons for this still ongoing attacks is its *counterintuive* character. This assessment includes the theoretical treatment of the speed of light, too.
Einstein asserted the speed of light to be always constant regardless of the motion of the observer. No matter how fast an observer is moving he or she will always measure the speed of light in vacuum to be 299.792, 458 meters per second. This statement is so obviously counter to commonsense, that the validity of Einstein's theory is still questioned.
But until now no one has yet found a convincing way to replace the relativistic interpretation of the speed of light c with an interpretation that is less counterintuitive. This almost collective experience seems to include the message, that the speed of light c is *truly* of counterintuitive nature.
If we take this message seriously, we have to conclude, that the relativistic interpretation can only be replaced successfully by an interpretation that is counterintuive as well. If we are looking inside modern physics for such an interpretation, we come inevitably to Quantum Mechanics.
In the double-slit experiment the counterintuitive being of Quantum Mechanics is described in the most direct way. Nowadays it is performed by using a coherent light source such as a laser beam. This beam illuminates a thin plate pierced by two parallel slits, and the light passing through the slits is observed on a screen behind the plate.

It is the wave nature of light that becomes visible while the beam is passing through the two slits. We can see, that bright and dark bands are produced on the screen — a typical interference pattern that would not be expected if light consisted strictly of particles. However, on the screen, the light is always found to be absorbed as though it were composed of discrete particles (photons). This behaviour of light is known as *wave–particle duality.* Its counterintuitive character becomes obvious, if we fire only one single photon at a time through the double-slit. The result is a single spot on the other side in a random location, indicating the particle-like nature of light. But if we keep firing one photon at a time and keep the previous spots, an interference pattern is building up, indicating that the photon is acting as a wave. A light particle seems thus to be able to travel through two slits at once. This result is so counterintuitive no one would believe this actually happens unless the experimental evidence were as overwhelming as it is. This phenomenon of the self-inference of a single photon is simply inexplicable in terms of classical physics.

In modern physics this counterintuitive character of light is no longer doubted. The wave-particle duality of light is a well-established concept. Curiously, the *Janu*s-faced character of light has never been applied to its speed. If we believe that the wave-particle duality of light is really of *fundamental* character it would be natural to assume, that the speed of light is also of dual nature, which means, c has two faces as well: one face, that is related to the wave-like pattern of light, and the other one, that is linked with its particle-like pattern.

This concept runs directly counter to our contemporary understanding of c, as it is explained by special relativity, because in Einstein's theory only the wave-like face of c (in the guise of its second postulate) is taken into account, whereas no reference due to a particle-like face of c can be found. If the concept of a wave-particle Duality of c were true, the relativistic interpretation of the c would only be half the truth.

In this paper some of the basic lines of this concept shall be presented. First of all I want to highlight the essential idea behind this concept. It is claimed that the wave-particle Duality of c has not yet been studied in a systematic manner, because a specific aspect of light has not been recognized as being part of it.

2 Einstein's Choices

From the viewpoint of classical physics the wave-particle duality of light represents a completely illogical concept. To give an example: Light waves can add destructively, light particles (if seen as a sort of bullets) can't do that. The wave-particle duality of light is thus - if interpreted in terms of classical physics - a logically contradictory concept.

If we believe in the *fundamental* validity of classical physics, we would certainly be inclined to resolve this contradiction in making a choice for

one of the two possible light theories. In this specific case our choice would probably be very clear: We would unhesitatingly conclude that light is a wave – and not a particle. In the following table this illogical character of the classical view of light is summarized.

Wave-Particle Duality		
Physical Pattern	**Wave**	**Particle**
Interference	**Yes**	**No**

Table no. 1 – The Illogical Nature of the Wave-Particle Duality (Classical View)

Today we know there is no need for any decision so far. According to the non-classical view light is indeed both a wave *and* a particle. The properties ascribed the particle-like face of light and the wave-like face of light may appear to contradict each other, but actually they don't.
That a wave-particle duality did not necessarily include any contradiction, this insight became visible for the first time when Einstein published his *Light Quanta hypothesis* in 1905. But it took more than twenty years until the wave-particle duality was generally accepted as a *fundamental* feature of Nature. When Einstein struggled with the speed of light c, no one (including Einstein himself) really believed in it.
This was something of a tragic circumstance, because the contradiction that arose in connection with the speed of light c was possibly not a contradiction between its constancy and the Galilean Principle of Relativity, as it is seen today, *but a contradiction between the two classical theories of light particularly concerning the dependence resp. independence of the speed of light from the speed of source.* According to Maxwell's theory the speed of light c did not depend on the speed of source, whereas in the particle theory (often called emission theory) it did.
If this property of light is consciously applied to our modern understanding of the wave-particle duality, the question unavoidably arises: *Could it be, that light is actually both dependent and independent on the speed of source at the same time?* This paper bases on the hypothesis, *that it could in fact be…* In the following table this hypothesis is summarized:

Speed of Light c		
Physical Pattern	**Wave**	**Particle**
Speed of Source	**Not-Dependent**	**Dependent**

Table no. 2 – The Wave-Particle Duality of the Speed of Light c

But at the end of the 19th century no physicist would have identified this specific contradiction as a problem that had to be solved. At that time it was almost collectively believed that the wave theory of light (i.e.

Maxwell's electrodynamics) was the final word. No physicist didn't believe seriously in the particle theory of light. Albert Einstein was in fact the only physicist, who was already in touch with the problem.
If we look under the surface of the contradiction that he had finally identified as the essential problem (i.e. the contradiction between the Relativity Principle and the Constancy of the Speed of Light) the contradiction that is claimed to be *no real* contradiction (see table no. 2) becomes visible.
In 1905 the Galilean Principle of Relativity was intimately connected with the classical particle theory of light: Light particles were seen as a sort of ballistic projectiles that moved through empty space in accordance with this principle. This view implied the speed of light particles being dependent on the speed of the source.
The Constancy of the Speed of Light c was in close relationship to the classical wave theory of light (i.e. Maxwell's theory of electromagnetism). In 1905 this theory based still on the assumption that light waves propagated in a material medium, like sound waves in air – a medium that was commonly called the »luminiferous ether«. It was thus concluded that the speed of light - being fully determined by the properties of ether – was independent of the speed of its source. This property of the classical wave theory being independent on the speed of source is obviously in contradiction with the classical particle theory, in which the speed of light depends on source's speed.
Although Einstein was certainly aware of this contradiction, he didn't solve this contradiction. As Quantum Mechanics was still in the distant future, one could come to the conclusion that in 1905 it was simply impossible for *every* physicist (including Einstein himself) to believe in the wave-particle duality of light at all. But remarkably Einstein was already aware of it. In 1909 at the Naturforscher convention in Salzburg, he surprised his colleagues with the farsighted prediction, that the next phase of development in theoretical physics would bring a theory of light that might be understood as kind of a fusion of the wave and the particle theory of light. [1]
Although Einstein wrote his paper on special relativity four years earlier it can safely be assumed that he already knew about the wave-particle duality of light in 1905. He could thus have recognized – at least in principle - that the contradiction between the particle and the wave theory of light as it is shown in table no. 2 had to be solved. But he should solve the contradiction between the Constancy of the Speed of Light and the Principle of Relativity – and we know, too, why he did this.
Actually, Einstein considered the wave-particle duality – right from the beginning of his career - only as a *preliminary* to a true theory, but not as a *fundamental* principle. [2] He sought therefore consequently for alternative solutions of the wave-particle-contradictions without getting involved too deeply into this strange field. To meet the challenge connected with it he attempted *to avoid any exclusive decision in favor of one of the two classical light theories.*

As it was extremely difficult to find an appropriate way to do this, he came finally to the conviction that only the discovery of *a universal formal principle* could help – and he should actually find such a principle: It is the "Principle of Relativity".[3] It is indeed an astonishing feature of this principle that one does not need to know whether light is a wave or particle. Whatever light is, it must conform to this principle. Consequently, if the Principle of Relativity is applied, there is no need to make a choice for or against a specific theory of light. It holds regardless of what light is.
In modern physics this *independence* of the Principle of Relativity is considered of being the strength of special relativity, but this independence is actually limited: *It does not include the speed of light.*
As far as the speed of light is concerned, special relativity includes a principal choice *in favour of the wave theory of light*. It is explicity expressed as its second principle. This principle states, that the speed of light c does not depend on the speed of source. This statement is an essential property that Einstein has distilled from the wave theory of light (i.e. electrodynamics). It became also known as *Light Postulate.* This postulate is shown in the following table:

Light Postulate		
Physical Pattern	**Wave**	…
Speed of Source	**Not-Dependent**	…

Table no. 3 – The Light Postulate

As the Light Postulate is stated as a universal principle like the Principle of Relativity itself, it is a fundamentally fixed choice in favour of the wave-like face of c. With this choice the universal scope of the Principle of Relativity is thus ultimately restricted. It may be independent with respect to almost every property of light, but with respect to this specific property (i.e. its speed) it is not independent. The Principle of Relativity is instead of that *exclusively* related to this specific face. Just this exclusive relationship implies a fundamental weakness of special relativity – a sort of blind spot with respect to the speed of light c: *It makes the perception of the other face of c (i.e. the particle-face) almost impossible.*

3 The Hidden Face of c

If we want to explain this fundamental weakness of special relativity an *identical* parametrization of the two faces of c is the most likely explanation. This identical parametrization of c can be expressed best in terms of natural units. That means, the equation c = 1 holds for both the wave-like face of c and the particle-like face of c. It is just this specific

demand which I am calling the *Dual Parametrization of c.* It is summarized in the following table:

Speed of Light c		
Physical Pattern	Wave	Particle
Speed of Source	Not-Dependent	Dependent
Parameter	**c = 1**	**c = 1**

Table no. 4 – The Dual Parametrization of c

If the particle-like face of c is equally parameterized like the wave-like face of c, then it is almost impossible to get in touch with this face *if judged from a decidedly relativistic point of view.* It remains in the dark. This becomes obvious, if we look at the two fundamental experiments of special relativity, that is, the *Michelson-Morley experiment* (MM-Exp) and the *Kennedy-Thorndike experiment* (KT-Exp).
These two experiments were intended to test the validity of the Principle of Relativity. In case of the MM-Exp it should be examined whether the observer's velocity relative the ether system depends on the *direction* of the motion or not, whereas in case of the KT-Exp it should be examined wether the observer's velocity relative to the ether system depends on the *magnitude* of the motion or not.
But these two experiments were built up in a way, that has repeatedly led to misinterpretations: Both experiments were *exclusively* adressed to the speed of light, in particular to its constancy. In both cases it was therefore asked one and the same question: *Are there any deviations with respect to c?* Or, in terms of natural units: *Does the equation of c = 1 hold in both cases?*
As in both cases the constancy of light (i.e. c = 1) has been confirmed, the MM-Exp & the KT-Exp were often interpreted as an experimental proof of the second postulate of special relativity (i.e. Light Postulate). But nowadays this interpretation is unequivocally called a misleading one: According to the orthodox relativistic interpretation »no-deviations« of c means *no* observable motion with respect to the hypothetically preferred frame of the ether – neither with respect to the *direction* nor with respect to the *magnitude*.
This interpretation is almost collectively considered of being the correct relativistic interpretation of the MM-Exp & the KT-Exp. But if we judge these two experiments on the background of a »Wave-Particle Duality of c«, a surprising insight comes to light which has been remained hidden until now: If there are really two faces of c, both parametrized in the same way, that is, c = 1, *then the relativistic interpretation of their two fundamental tests is by no means unambiguous, because special relativity is only asking, wether the equation of c = 1 holds or not*. In other words, Einstein's theory is exclusively asking, whether the speed of light is constant or not, it does not differ in any way between a wave-like face of c and a particle-like face of c. And according to Einstein there is even no need to make this

distinction, since the Principle of Relativity is considered of being valid regardless of whether light is a particle or a wave.
But what is commonly understood as the particular strength of special relativity, proves - viewed on the background of a »Dual Parameterization of c« - to be a fundamental weakness, because the Principle of Relativity is not *fully* independent. It is in fact exclusively related to the wave-like face of c. And just this exclusive relationship implies a blind spot of special relativity: Whenever the equation of c = 1 is experimentally confirmed, it is believed, that the wave-like face of c has been confirmed, too. But this belief may be wrong, since the particle-like face of c obeys also the equation of c = 1. If the concept of a Dual Parametrization of c holds, then special relativity is indeed only half the truth: *It does not include as requested by a wave-particle duality of c a description of the particle-like face of c.*
Though this other face of c seems still to be hidden, it is nonetheless thinkable, *that it has already been discovered but not recognized as such.* As in the MM-Exp & the KT-Exp the constancy of the speed of light (i.e. c = 1) has been examined twice and found to be true twice, it is near at hand to conclude, that *possibly* the existence of the two faces of c has been confirmed – and not the validity of the Principle of Relativity.
If the wave-like face of c has been discovered by the MM-Exp, as it is often assumed, then it is very likely that the particle-like face of c has been discovered by the KT-Exp.[4] This somehow »quantum-mechanical« interpretation of the MM-Exp & the KT-Exp is summarized in the following table:

The Two Faces of c		
Physical Pattern	Wave	Particle
Speed of Source	Not-Dependent	Dependent
Parameter	c = 1	c = 1
Experiment	**MM-Exp**	**KT-Exp**
Year of Discovery	**1887**	**1932**

Table no. 5 – The Discovery of the *Janus*-faced Character of the Speed of Light c.

It is admitted that all the statements presented in this paper including the last one are far from being a physical theory. To make a step towards such a theory I want to make some remarks, how the most critical point of the proposed concept of a Dual Parametrization of c, that is, its intrinsic logical contradiction, could be »mitigated« – at least so far that a contradiction with the most relevant observations is excluded.

4 The Source Postulate

If the wave-particle duality of c is presupposed of being a meaningful concept, then the question naturally arises: Why did Einstein reject the particle-like face of c at all? What was the deeper physical reason?

We know Einstein rejected the particle-like face of c, because the behavior of classical light particles was described by the *Galilean transformations* – and not by the *Lorentz transformations*, as classical light waves did. Having recognized just this inconsistency (as the root of the contradiction between the Principle of Relativity and the Light Postulate) this recognition was indeed one of Einstein's groundbreaking steps on his path to special relativity. In the following table this inconsistency is shown.

The Two Faces of c in 1905		
Physical Pattern	Wave	Particle
Transformation Set	Lorentzian	**Galilean**
Speed of Source	Not-Dependent	Dependent
Parameter	c = 1	**c > 1**

Table no. 6 – The Two Faces of c in 1905 – A historical Snapshot

The formal core of this inconsistency is the way how velocities are composed in these two transformation sets. According to the Galilean transformations co-linear speeds are composed in a simple additive manner. In equation (1) this is shown.

$$\mathbf{c = c' + } v \tag{1}$$

If this law is applied to the speed of light, then c is only constant in an inertial frame, in which the observer is being at rest with respect to the source. See: equation (2).

$$\mathbf{c = c' + 0 = c'} \tag{2}$$

In all other cases the speed of light wouldn't be constant. Every moving observer would measure a different value, depending on its own relative velocity, because the speed of light being dependent on the speed of souce is summed up. The final speed of light would thus *the own speed of light c plus the speed of the source v*. In other words, according to the classical particle theory of light light would propagate in different direction with different velocities; sometimes with speeds even greater than c: ***c* > 1.**

For Einstein it was simply impossible to set up any sort of reasonable wave (i.e. electromagnectic) theory of light, which accomplished this particle-like feature. [5] He was instead deeply convinced that the speed of light was always the same in all directions, as it was suggested by the wave theory of his time. Therefore, he assumed, the eq. (3) must be valid for all observers.

$$\mathbf{c = c'} \tag{3}$$

Einstein solved the task connected with this assumption – as already mentioned - by replacing the Galilean transformations by the Lorentz transformations. This solution implied a *new velocity addition rule*; a rule that perfectly fitted to the demand of eq. (3). This new rule possessed an unusual, but highly effective property in this regard: *The speed of light was*

not changed in any way if composed with another subluminal speed. [6] In the following equation (4) this property is shown.

$$\mathbf{c} = \frac{c+v}{1+\frac{cv}{c^2}} = \mathbf{c'} \tag{4}$$

This eq. (4) is highly effective, because it allowed not only Einstein to get rid of the inconsistency, with whom he wrestled, it makes it possible to remove the inconsistency as it is shown in table no. 6, too: If the particle-like face of c is connected with eq. (4), then the final speed of light is always the same, in full accordance with eq. (3). [7] If table no. 6 is updated accordingly, following picture emerges.

The Two Faces of c in 2012		
Physical Pattern	Wave	Particle
Transformation Set	Lorentzian	**Lorentzian**
Speed of Source	Not-Dependent	Dependent
Parameter	c = 1	**c = 1**

Table no. 7 – The Two Faces of c, updated 2012.

Though it seems to be possible to eliminate a central inconsistency of the relationship between the wave-like face of c and its particle-like face, this possibility involves a highly counterintuitive consequence: *The speed of a particle-like beam of light would always be measured as being constant, regardless wether its emitting source is at rest or moving with respect to the observer.* This consequence – which I am calling the *Source Postulate* – is indeed counterintuitive: How can the speed of light depend on the motion of the source but yet being the same, no matter how fast the source is moving?
As the Source Postulate sounds very similar to the Light Postulate it is near at hand to interprete it *as the complementary counterpart of Einstein's postulate*. This is shown in following table.

Source Postulate		
Physical Pattern	…	**Particle**
Speed of Source	…	**Dependent**

Table no. 8 – The Source Postulate

If one holds the idea of the dual nature of c to be a promising concept, there are indeed a lot of questions that have to be answered: *How are the Source Postulate and the Light Postulate related to each other? Do we have to change our understanding of space and time? If so, how? And how is the Principle of Relativity related to these two Postulates? And how can the Dual Parametrization of c be tested experimentally in an unambiguous way?*

References:

[1] A. Einstein 1909c (Doc. 9), pp. 482-483
[2] A. Pais; 'Subtle is the Lord…' – The Science and the Life of Albert Einstein; 1982, p. 462
[3] The Collected Papers of Albert Einstein, Vol. 2, The Swiss Years: Writings, 1900 – 1909, p. xvii
[4] H. Hansen, Helmut; *The Hidden Face of c, Or the True Meaning of the Kennedy-Thorndike experiment*; *Proceedings of the NPA*, 2011, Volume 8, pp. 240-245
[5] J. Stachel; *Einstein and Michelson – The Context of Discovery and the Context of Justification*, Astron. Nachr., **303** (1982) I, p. 51
[6] A. Einstein, *On the Electrodynamics of Moving Bodies,* 1905b, § 5.
[7] J. Stachel; *Einstein's Light-Quantum Hypothesis, or Why Didn't Einstein Propose a Quantum Gas a Decade-and-a-Half Earlier?* In: Einstein – The formative Years, 1879 – 1909, Einstein Studies 2000, p. 240.