



Comment on Information and Dualism

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ABSTRACT

The similarities between the hypothetical medium of light propagation, the aether, and the Dirac-type negative sea are discussed. In particular, it is argued that when the negative sea is identified as the observer's reference frame, it may be equivalent to the medium of light waves. In fact, this equivalence is related to the natural interpretation of the wave-particle duality where the light wave is propagating through the reference frame of the observer, i.e., the wave-like property, while the particle-like aspect is shown as the eigenvalue outcome of the measurement. This result lies within standard quantum theory, yet removes the weirdness of the wave-particle duality that existed previously.

Key Words: Computation, Information, Duality

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Introduction

Light has shown mysterious aspects in a number of ways, one of which is its dual nature. On the one hand, it exhibits the property of particles, while on the other, it shows the property of a wave as seen by the interference pattern in Young's double slit experiment. In fact, this property of the wave-particle duality is at the heart of the weirdness in quantum mechanics (Feynman, 1970) and has puzzled many people for over a century. Recently, with the development of quantum information science (Bennett *et al.*, 1984; Deutsch, 1985; Bennett *et al.*, 1993; Nielsen *et al.*, 2000), efforts have been made to closely examine the wave-particle duality from various perspectives (Wootters *et al.*, 1979; Jaeger *et al.*, 1995; Kim *et al.*, 2000; Jacques *et al.*, 2007; Liu *et al.*, 2009; Liu *et al.*, 2012; Jia *et al.*, 2014; Coles *et al.*, 2015). In order to illustrate a simple version of the wave-particle duality of light, the following aspects can be considered. As shown in Fig. 1, a single photon is shot from the source and passes through the 50/50 beam splitter. The photon goes to the left and right path, and the detector clicks at each end.

When the photon goes through two paths, it may be written as

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|L\rangle + |R\rangle) \quad (1)$$

where $|L\rangle$ and $|R\rangle$ are identified as the left and right path, respectively. Therefore, the wave-like property is exhibited when the state is in superposition as in (1), and the particle-like property is exhibited when one of the two detectors clicks, but not both.

Another puzzling aspect of light is its wave-like property in which it does not have a medium to propagate. This is strange considering waves generally have a medium in which to propagate, e.g., the sound the wave propagates through the medium of air. This has been one of the puzzling features of light since its wave-like property was noticed. In particular, this predicament led to conjecture about the possible existence of a medium, called aether, in which light could propagate. However, with the failure to detect the aether relative to the motion of the Earth in the Michelson-Morley experiment, the interest in the aether faded.

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However, the fundamental question of the mysterious nature of light and its constant speed, which disregards the addition of velocity rules that are usually applied, and the existence of a medium in which to propagate has remained.

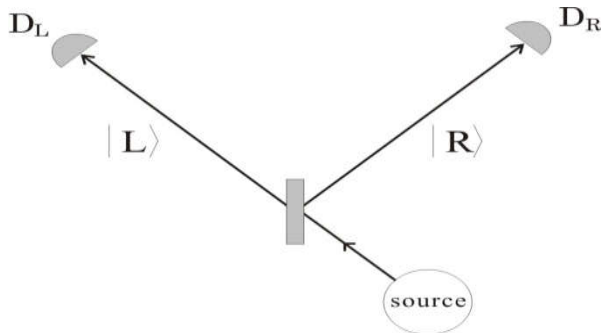


Figure 1. A simple version of the wave-particle duality. A single photon is shot from the source and passes through the beam splitter and follows the left ($|L\rangle$) and right ($|R\rangle$) paths at the same time, thus displaying a wave-like property, but when it reaches the detectors, only one of them clicks, thus displaying a particle-like property.

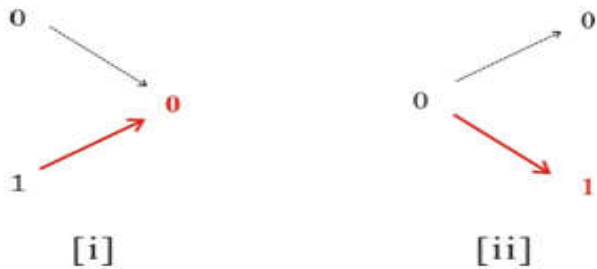


Figure 2. [i] Irreversible computation: Given two inputs, the output may be just one. This is irreversible in a sense that it is not possible to determine a single input given the output. [ii] Nondeterministic computation: a time-reversal process of the irreversible computation in [i]. Nondeterministic computation chooses the acceptable path which is the time-reversal of the irreversible gate.

A concept similar to the aether, namely, negative sea, has been proposed by Dirac for a completely different reason. In order to come up with an explanation of the negative energy value, he envisioned the vacuum to be filled with, similar to aether, a transparent fluid-like negative sea, which turned out to yield one of the fruitful theoretical predictions - antiparticles. Therefore, it can be seen that there are similarities between the Dirac-type negative sea and the aether. Indeed, Dirac had raised the possibility of aether (Dirac, 1951), but it did not gain much support. In this paper, we will try to argue these two may indeed be identical when we make an assumption where the negative sea corresponds to the reference frame of the observer. In particular, we will illustrate that the wave-particle duality in Fig. 1 has a natural interpretation so that it is not strange for a photon to take two different paths at

the same time as suggested by standard quantum theory.

Negative Sea as Reference Frame

Let us first review how the Dirac-type negative sea may be the reference frame of the observer by considering the process of irreversible computation and nondeterministic computation processes. As shown in Fig. 2 [i], irreversible computation (Landauer, 1961) refers to a process when two inputs, 0 and 1, may end up with a single output, 0. In such a case, given the output, it is not possible to identify the input. On the other hand, the nondeterministic computation may be considered as a time-reversal of the irreversible computation, such that, the input (0) may proceed to two different outputs (0 or 1) (for example, see (Song, 2014b)). However, as seen in Fig. 2 [ii], the nondeterministic computation chooses the acceptable path (i.e., to 1) as the time-reversal of the irreversible gate (where the input was 1). This is different from probabilistic computation where

it proceeds to 0 or 1 with $P = \frac{1}{2}$, for example.

In (Song, 2015), the universe model where the negative sea is taken as the observer's reference frame was proposed using the nondeterministic computation, i.e., nondeterministic computation evolves backwards in time, as in Fig. 3 [i], to fill the observable universe as negative sea. Here it chooses the path as a time-reversal process of irreversible computations since the big bang so that the total entropy corresponds to the entropy of the observable universe (Egan *et al.*, 2010). As seen in Fig. 3 [ii], the nondeterministic computation corresponds to the choice of the observable.

It is noted that the model in Fig. 3 was proposed in order to extend the subjectivity seen in quantum theory to the whole universe. Here, unlike the previous approach where it was assumed that physics seeks the objective reality, physics ought to provide a description between the observer and the object being observed (Song, 2012), as hinted in the standard Copenhagen quantum theory. Moreover, based on the asymmetry between the Schrödinger and the Heisenberg pictures (Song, 2008; 2012), it has been argued that not only is the subjectivity characteristic of physics research, but the existence should be as well. The subjective model in Fig. 3 is a specification of what is meant by the existence being subjective by arguing that the observer's choice, as nondeterministic



computation, evolves backwards in time to fill up the universe as negative sea.

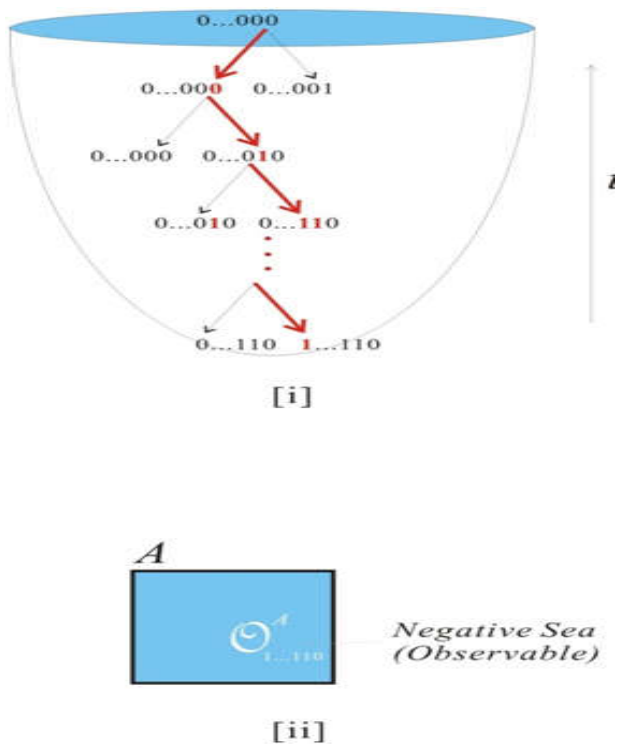


Figure 3. Toy subjective universe model with nondeterministic computation (Song, 2015), i.e., the observer's choice of the reference frame, [i] traveling backwards in time and [ii] filling up the space as negative sea to serve as the choice of an observable.

Duality and Aether

In order to consider the wave-particle duality in the proposed model in Fig. 3, let us adopt the notation in (Song, 2008) to represent the two-level quantum system - a qubit. Using a Bloch sphere notation, a qubit can be represented as a unit vector pointing at (θ, ϕ) with $v = (\sin \theta \cos \phi, \sin \theta \sin \phi, \cos \theta)$. Moreover, the observable, or the observer's reference frame, may be written similarly as a unit vector $e = (\sin \mathcal{G} \cos \varphi, \sin \mathcal{G} \sin \varphi, \cos \mathcal{G})$ that is pointing in (\mathcal{G}, φ) direction in a sphere. In order to accommodate the simple wave-particle model with a single photon in Fig. 1, let us assume $\phi = 0$ and the superposed state with equal probability, i.e., Eq. (1), may be written with $\theta = \frac{\pi}{2}$, such that $v' = (1, 0, 0)$, while the reference frame is set to remain still as $e = (0, 0, 1)$. This approach of considering dynamics of the state vector is the Schrödinger picture.

In the subjective model (Fig. 3), we posit that the dynamic part should be the observer's reference frame, i.e., e in this case, as in the

Heisenberg picture. Therefore, we will assume that while $v = (0, 0, 1)$ remains, the observable represents the superposition of the left and right paths in Fig. 1, i.e., $e' = (-1, 0, 0)$. In the previous section, we discussed that the negative sea can be considered as the evolution of the observer's reference frame. In the wave-particle duality case (Fig. 1), the reference frame of the observer would correspond to e' evolving backwards in time. One of the central issues of the wave-particle duality is that the photon seems to be taking two different paths at the same time, as seen in Fig. 1. According to the proposed model, the simultaneity of the two paths is indeed true except its existence is within the reference frame of the observer, i.e., in the negative sea. Therefore, the wave-like property happens in the negative sea as an evolution of the observer's reference frame, while the measurement outcome, or particle-like aspect, yields the eigenvalue outcome of +1 or -1, i.e., left or right detector clicks, respectively.

Moreover, the proposed duality interpretation implies that the propagation of light wave (the qubit in our discussion) takes place in the negative sea. Therefore, the model of the observer's reference frame as negative sea filling up the universe suggests that the aether should be identified as the negative sea. That is, the medium of light should correspond to the reference frame of the observer. Therefore, one can see that while there are similarities between the aether and Dirac-type negative sea, it is when we identify the negative sea as the reference frame of the observer, it yields a natural interpretation of the wave-particle duality, and the equivalence between the aether and the negative sea takes place.

Remarks

One of the most puzzling features revealed in the wave-particle duality experiment was whether the photon was going through the left or right or both paths at the same time. Indeed, this wave-like property of superposition has been shown to be useful in quantum information technology and quantum computation by representing the basic element of information as a superposed bit, i.e., 0 and 1 exist simultaneously. According to the proposed model, the superposition is indeed true, as expected from a large number of experiments all confirming standard quantum theory (for instance, see (Bell, 1964; Aspect *et al.*, 1982; Tittel *et al.*, 1998; Gröblacher *et al.*, 2007)), except that it is occurring in the negative sea of the observer's



reference frame as hinted in the Heisenberg picture dynamics (Song, 2008). It should be noted that the interpretation of the wave-particle duality discussed in this paper is within standard quantum theory, i.e., the wave-like property is exhibited by unitary transformation, and the measurement result follows the usual probability rules in quantum theory.

Finally, the identification of aether as a reference frame of negative sea provides further support for the ongoing effort in the subjective model (Song, 2012) proposed initially from the symmetry breakdown between the Schrödinger and the Heisenberg pictures due to self-observation of consciousness (Song, 2007). The current objective model of the universe, where it assumes that physics pursues objective reality and that existence is objective, suffers from a number of aspects that seem to be problematic at the fundamental level. One of them is the black hole information problem where its radiation seems to violate quantum theory (Hawking, 1976). In (Song, 2014a), it has been shown that when the subjective universe model is taken, black hole radiation may be considered as a process of quantum measurement, which thus avoids its contradiction with quantum theory. Another puzzling feature of the current objective model is the number of strange aspects of quantum behavior, such as the wave-particle duality. The discussion in this paper adds one more reason why the subjective model needs to be taken as opposed to the objective one: it yields a natural explanation of the duality and the medium of light.

Acknowledgments

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