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Can the Stark–Einstein law resolve the measurement problem from an *animate* perspective?

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ABSTRACT

Analysis of the Stark–Einstein law as it applies to the retinal molecule, which is part of the rhodopsin molecule within the rod cells of the retina, reveals that it may provide the solution to the measurement problem from an *animate* perspective. That it represents a natural boundary where the Schrödinger equation or wave function automatically goes from linear to nonlinear while remaining in a deterministic state. It will be possible in the near future to subject this theory to empirical tests as has been previously proposed. This analysis provides a contrast to the many decades well studied and debated *inanimate* measurement problem and would represent an addition to the Stark–Einstein law involving information carried by the photon.

> Nobody knows what quantum mechanics says exactly about any situation, for nobody knows where the boundary really is between wavy quantum systems and the world of particular events.
>
> John Bell

1. Introduction

The measurement problem in quantum mechanics deals with the issue of how or whether wave function collapse occurs when a physical quantity is measured and what role measurements play in quantum mechanics (Wigner, 1963; Leggett, 2005; Adler and Bassi, 2009). How does the wave function go from linear to nonlinear? The wave function evolves continuously according to the Schrödinger equation as a linear superposition of different states, but actual measurements always find the physical system in a definite state with regards to physical quantities such as photon polarization or electron spin. We cannot predict precise results for measurements of this nature, only probabilities. Any future evolution is based on the state the system was discovered to be in when the measurement was made, so the measurement "did something" to the system that is not obviously a consequence of the Schrödinger evolution.

There appears to be a major difference between *inanimate* and *animate* "measurements", which is critical to the issue of any discussion of the measurement problem from this perspective. In the *inanimate* instance we have been mainly interested in measuring superposed photon polarization or superposed electron spin states, where the total of the information possessed by the photons concerns polarization states, and for electrons their spin states. As is well known, the outcome probabilities are given by the absolute value squared of the corresponding coefficient in the initial wave function, or the Born 50-50 rule, and therefore the outcomes are not predictable in advance. Since we prepare these superimposed states, they only contain the information which we are interested in deriving when we set up the experiment. I.e., we are only interested in very limited polarization or spin outcome information, especially as regards the measurement problem.

Since this proposal will be dealing only with photons, it is important to point out that the photon is a fundamental carrier of information, possessing numerous information carrying degrees of freedom in addition to polarization. These include frequency, phase, arrival time, orbital angular momentum, linear momentum,

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entanglement, etc. This can be considered as *intrinsic* or *inherent* quantum information possessed by a photon, in contrast to the additional *extrinsic* classical information which can be acquired by the photon from the natural classical *environment* with which we are all familiar from a visual perspective, and which can possess an infinite number of definite visual possibilities. For example, a photon that has been emitted or scattered by the text projected on a computer screen or printed on a sheet of paper, carries information of this text at the quantum level and an observer acquires this information by intercepting a small fraction of these photons (Zurek, 2007). This classical information has been reduced down to the quantum level by the photon(s) and represents an exact copy or copies with accompanying wave functions.

2. State preparation prior to the operation of the Stark–Einstein law

In this *animate* measurement instance, these photons have either naturally scattered off of a multitude of different surfaces or been naturally emitted by various sources (mostly without our specific input), and they therefore contain *classical environmental information* which is constantly being presented to the retina (Zurek, 2007). In this specific visual case, the preparation of these states by Nature means that the outcome probability results in the *naturalization* of the Born rule (as was previously pointed out), so that it is no longer a 50-50 result but, 100% (Thaheld, 2009)! (It has been recently brought to my attention that this is the equivalent of saying "probability 1", as encompassed by the deterministic tenets of QBism, a topic which will be discussed later in this paper). And, since Nature prepares these states (again, mostly without our specific input), they can be considered as a true picture or representation of *classical environmental information* as expressed in their wave functions and can therefore be regarded as *pure* states representing maximal knowledge about these states and their preparation (Chiribella et al., 2011; Hardy, 2001). There is also the possibility that we might be dealing with *mixed* states which are part of a larger *pure* state, in which case it would still be possible to describe each physical process with maximum information. This is also known as the "*purification principle*" (Chiribella et al., 2010).

Now, with this picture in mind, exactly what would constitute a measurement and, at what point might superpositions break down and definite outcomes appear in an *animate* visual setting? At this point we bring in the Stark–Einstein law.

3. Stark–Einstein law and retinal molecule

The Stark–Einstein law is named after Johannes Stark and Albert Einstein, who independently formulated the law between 1908 and 1913 (Cox and Kemp, 1971). It is also known as the photochemical equivalence law or photoequivalence law. In essence it says that each quantum of light that is absorbed by a molecule will cause a (primary) chemical or physical reaction in that molecule. And, although it was first proposed for physics and chemistry in the inorganic material world, it has a great potential in the field of biology as outlined herein from an *information* perspective.

It is important to stress here, for the first time to the author's knowledge, that in addition to the chemical or physical reaction mentioned, that *classical information* acquired from the *environment* by the photons, and thereby reduced to the quantum level, will also be passed on, not only to all the inorganic and organic molecules but, especially to the very receptive retinal molecules, to be further utilized, based upon the quantum detection efficiency of the retinal molecules. The retinal molecule is in an extremely unique position with regards to nearly all the other numerous organic and inorganic molecules in this regard, in being able to utilize this *classical environmental information* rather than it being discarded and lost for all time. This is the concept which the author feels should be a natural addition to the S–E law.

Let us now have a photon be absorbed by retinal, which is a light sensitive molecule found in the photoreceptor cells of the retina. Retinal $C_{20}H_{28}O$ is the fundamental chromophore involved in the transduction of light into electrical signals, which are processed by other cells in the retina and then sent to the brain where they produce visual images (Baylor, 1996; Rieke and Baylor, 1998; Whikehart, 2003).

To briefly recaptulate, there are $\sim 10^8$ rod cells in each human eye or retina, with $\sim 10^8$ rhodopsin molecules in each rod cell and, with each rhodopsin molecule containing a retinal molecule (Whikehart, 2003). Rod cells are natural photodetectors and represent a natural biological interface with photons. They convert incident light into electrical signals, which are then sent to the brain via the optic nerve. It is critical to this analysis to mention that all the rhodopsin molecules are *identical*, as are all the retinal molecules. The rod cell absorbs photons with a quantum detection efficiency of $29 \pm 4.7\%$, and absorbed photons produce detectable output signals (Baylor, 1996; Rieke and Baylor, 1998; Phan et al., 2013). This means that only 1 out of the $\sim 10^8$ rhodopsin molecules within each rod cell, and its embedded retinal molecule, is involved sequentially each time in one successful absorption event which encompasses photoexcitation, photoisoimerization and phototransduction. Simultaneously, exposed to a continuous photon stream from the environment, the other $\sim 10^8$ rod cells are undergoing this same process, subject to the quantum detection efficiency. The only probabilistic question, which is of no importance to us in this analysis, is which one of the identical $\sim 10^8$ retinal molecules in each rod cell, will end up successfully absorbing a photon each time. Once a retinal molecule absorbs a photon a lengthy process begins, culminating in an amplified current ~ 1 pA in amplitude and lasting ~ 200 ms, resulting in 2–3 signals in the rod cell's synaptic junction, which eventually leads into an axon and from there to the optic nerve. (Baylor, 1996; Rieke and Baylor, 1998; Whikehart, 2003). I.e., the initial quantum *environmental information* has been amplified back to the classical level in a reversible fashion. In addition, the discs within the rod cell which contain the retinal and rhodopsin molecules, along with these molecules, are continuously being shed and generated in a cyclical fashion (Mazzolini et al., 2015).

Prior to successful absorption, which ultimately constitutes phototransduction and a detectable output signal, a photon can be considered to be either a wave or a particle but, it has to ultimately be a particle in order to be absorbed by this molecule, in line with the S–E law. When a photon is absorbed by the retinal molecule into one of the π bonds found between carbon 11 and 12, it passes on its energy, and more importantly its *information* simultaneously, to an electron in the highest π orbital, which then jumps into a higher π^* electron orbit (Thaheld, 2008). One now has to ask the question as to whether the wave function collapsed at the instant of absorption when the photon interacted with the π electron and passed on its energy and *information*? In any case, whenever and wherever this collapse or absorption takes place, the outcome will be the same each time after repeated measurements, and it will be governed by the S–E law, which acts as a boundary between linear and nonlinear states. And, this *information* initially derived from the *classical environment*, will pass from an *inanimate* state to an *animate* state at this point in time.

We now go from Schrödinger linear deterministic superposed states, which can be *pure* states or *mixed* states as part of a *pure* state to a Schrödinger nonlinear deterministic collapsed *pure* state, both of which states possess the same *information* every time but, in different amounts (Chiribella et al., 2011)! It is just that the superposed states possess more of this same *information*, while the