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The Strange Nature of Quantum Entanglement: Can Observers of Entangled Photons Become Entangled With Each Other?

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This paper seeks to extend my recent work on quantum perception (Rosen, 2021) to the phenomenon of quantum entanglement. In the first section, I summarize the earlier work, noting how the conventional approach to observing photons is rooted in an objectivist philosophy that serves as an obstacle to probing the underlying quantum reality. In the summary provided, I bring out the intimate relationship between observer and observed in the quantum world, and the need for a new, proprioceptive mode of observation linked to phenomenological philosophy. The second part of the paper builds on the earlier effort by applying the proprioceptive observation of photons to the phenomenon of entanglement. The basic proposition is that proprioceptive observers of entangled photons may become entangled with each other. I propose an experiment that tests this hypothesis. In concluding, I explore the possibility that a quantum internet of proprioceptively engaged participants could create an ontologically entangled society.

Keywords: phenomenology, proprioceptive observation, quantum entanglement

The present paper aims to broaden my work on quantum perception (Rosen, 2021) by including the phenomenon of quantum entanglement and its philosophical and social implications. In this opening section, I summarize the previous work.

The 2021 paper takes as its point of departure evidence that human beings are capable of detecting single photons (Holmes et al., 2018; Holmes, 2019; Tinsley et al., 2016). Beyond confirming that single-photon perception occurs, physicists

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have set their sights on the even larger aim of pushing human vision to the point of probing "the very foundations of quantum mechanics" (Ananthaswamy, 2018). Mainstream quantum theory holds that prior to laboratory observation, the photon exists as a probabilistic wave whose potential states are superposed, rather than being definitively given in one state as opposed to another. Then, when the transition is made from the submicroscopic quantum world to the macroscopic realm of classical laboratory observation, the photon's quantum wave collapses into a single state. On this assumption, probing "the very foundations of quantum mechanics" means that, more than just perceiving the single photon, perception would deepen to experience directly the superposed states of the quantum wave that underlie the photon. Thus, in speaking of the prospect of going beyond the detection of solitary photons to test "the perception of superposition states," Holmes et al. (2018) were indicating that we may be able to observe the photonic wave while its quantum states are still superposed, before the wave collapses.

In order to understand better what quantum perception might actually entail, in my 2021 paper I examined several of the leading interpretations of quantum mechanics and discussed their limitations. After many decades of puzzling over the nature of quantum reality, theorists continue to favor the Copenhagen interpretation (see Schlosshauer, Kofler, and Zeilinger, 2013). This attests to the fact that the quantum world has remained largely a mystery, for the Copenhagen approach relinquishes the aim of achieving a deep understanding of the quantum domain. Instead, it satisfies itself with a pragmatic strategy essentially limited to using its equations to predict the behavior of subatomic particles.

An obstacle to grasping quantum reality for many theoretical approaches lies in their implicit adherence to the classical paradigm of objectivism. This still dominant philosophy locates reality in an external world that is taken as independent of human perception or mind. Therefore, in the objectivist's quest for knowledge, the effect of perception per se on the "objective" phenomenon being investigated is largely ignored. But when we consider the phenomena of the quantum realm, what we find is that the observing subject and the object observed are linked in such a way that objectivism's mind-independence is opened to question. Confronted with the unique subject–object relationship evidenced in microphysics, objectivists cannot so easily discount the observer by regarding her as a purely passive witness to objective fact and this has led to interpretations of quantum mechanics that part company with objectivism. In my 2021 article, I considered both mind-independent and mind-dependent approaches and came to the conclusion that quantum mechanics needs to be regrounded in a philosophical outlook that provides the strongest possible support for the intimate interdependence of subject and object. I proposed that this criterion can best be met by ontological phenomenology (see Heidegger, 1927/1962, 1964/1977; Merleau–Ponty, 1964, 1968).

In the phenomenological interpretation I offered, the underlying quantum reality is regarded as fundamentally psychophysical. This is a reality wherein no peremptory division exists between mind and matter or subject and object. In such a world, the photonic wave could not be a probabilistic superposition of objective quantum states that could be set before a detached observer. Phenomenologically understood, what are superposed in the photonic wave are the observer and observed themselves. And this is consistent with the paradoxical nature of the photon.

In my 2021 article, I cited cosmologist Arthur Young's (1976) comment that the photon "is not an objective thing that can be investigated as can an ordinary object"; light "is not seen; it is [the] seeing" (p. 11). Or, as Sachs (1999, p. 14) put it, light is not "a thing on its own," not an independent object; instead it is the inseparable blending of subject and object. However, when the photon is brought into the laboratory, the classical ideal of "objective observation" tacitly prevails and the researcher adopts an observational posture of detachment in which the photonic wave is objectified. The result is that the radiant psychophysical wave loses its coherence, collapsing into mere matter, a mere object appearing before the observing subject.

My suggested remedy for this problem employs an unorthodox form of observation known as *proprioception*. While ordinary observation involves the perception of what lies outside of oneself, proprioception is a mode of self-observation. Etymologically, to perceive is to "take hold of" or "take through" (from the Latin, *per*, through, and *capere*, to take), whereas the word "proprioceive" is from the Latin, *proprius*, meaning "one's own." Literally then, proprioception means "taking one's own," which can be read as a taking of self or "self-taking." The term finds its most common usage in physiology where it signifies an organism's sensitivity to activity in its own muscles, joints, and tendons. But physicist–philosopher David Bohm (1994) spoke of the need for "*proprioceptive thought*" (p. 229), which he viewed as a certain kind of meditative act wherein "consciousness … [becomes] aware of its own implicate activity, in which its content originates" (p. 232). What I suggested in 2021 is that the observer of the photon would need to operate proprioceptively, to be aware of her own implicate activity as she views the photon, if she is to counteract an objectification of the photonic wave that would collapse it.

The proprioceptive observational posture is not one of disengaged objectivity that splits observer and observed. Rather, it is aligned with the inherently psychophysical character of the quantum world. In observing the photon proprioceptively, the observer would maintain awareness of her own act of observing. Here attention would move counter to the direction in which conventional observation occurs. The ordinary movement of perception outward toward the photon would at once be accompanied by an inward passage to the source of observation. The observer thus would interact with the photon through an embodied sense of her own process of observing as it is occurring in the moment. Just as I can obtain a proprioceptive (or kinesthetic)[1] sense of the muscular activity in my fingers as I type these words, the photon's observer should be able to obtain (perhaps with some training and practice) a sense of the movement of her eyes as they attempt to engage with the photon. In counteracting the outward movement of attention by simultaneously drawing perception back in upon itself, the observer would no longer be limited to viewing the objectified, already collapsed photonic wave. She could now gain a concrete sense of the otherwise unnoticed process by which the psychophysical wave has been collapsed, a view that would include the initial state of subject–object superposition. It is in this way that the collapse would be counteracted.

In my 2021 paper, I clarified what the proprioception of visual activity entails by introducing the work of psychiatrist and brain researcher Trigant Burrow. The classical observer engages in the kind of objectifying behavior that Burrow located in the "cerebro–ocular" region (1953, p. 526), that is, in the cerebral cortex of the brain and in the organ of vision associated with it. Burrow pointed out that it was through the phylogenetic development of the brain's cortex that the perceptual, linguistic, and symbolic operations of the classical subject first arose. Therefore, to become tangibly aware of this sort of activity, it seems one would need to bring proprioceptive attention to one's cerebral cortex. To that end, Burrow conducted experiments in which the observer "adhered consistently to relaxing the eyes and to getting the kinesthetic 'feel' of the tensions in and about the eyes and in the cephalic area generally" (1953, p. 95). Elsewhere (Rosen, 1999), I proposed a further specification of the tensions in question.

Ordinary binocular vision operates in such a way that our eyes function in concert to bring a particular object into focus. This act of binocular convergence is a well-established neurophysiological habit. It seems to follow from Burrow's analysis that binocular convergence is a process of visual objectification that is closely associated with the symbolic operations of the cerebral cortex. Burrow came close to stating this explicitly when he related the advent of objectifying perceptual activity (what he called "ditention," i.e., divided attention) to the elaboration of cortically based linguistic operations, and related language to the movement of the musculature in and around the eyes. The ocular–facial movements described by Burrow thus can be said to involve the shifting of optical focus from this object

[1] Historian of science Roger Smith (2020) discusses the distinction between the terms "proprioception" and "kinesthesia." Strictly speaking, "kinesthesia" is a psychological term referring to conscious sensory awareness of movement in one's body, whereas "proprioception" is a physiological term indicating largely unconscious sensitivity to bodily activity (as noted above). However, Smith points out that the meanings of kinesthesia and proprioception are very often confused in the literature or taken as synonymous. In the present paper, I do not generally use the word "kinesthesia." Instead I employ the word "proprioception" in Bohm's broad sense of self-awareness, which is grounded by the word's etymological meaning, "self-taking."

to that, in continual acts of binocular convergence. And the proprioception of binocular convergence is what is needed for the observation of the photonic wave.

Burrow's initial efforts were followed by a program of research in which subjects were studied while practicing proprioception as they engaged in activities such as reading and viewing pictures. In this research, participants proprioceived the eye–brain nexus in the course of observing ordinary objects in a macroscopic setting. What is presently of interest is the prospect of observing the submicroscopic quantum domain via the proprioceptive perception of the photonic wave.

Operating proprioceptively, the observer of the radiant wave would direct her awareness to the eye–brain nexus as her optical muscles seek to fix the wave via binocular convergence. Whereas in ordinary observation the observer is not cognizant of her own internal process, with proprioception her interiority is consciously included, as is required for entering a realm not amenable to splitting observer and observed. While attempting to see the wave in a strictly "objective" way would only collapse it and destroy its subject–object coherence, observing it proprioceptively should enable the observer to view the coherent wave before its collapse.

Note that when the viewer would bring her attention to the convergent action of her eyes, the photonic wave falling on her retina would not merely register as an objective phenomenon occurring separately from her subjective viewing process but would be recognized as an integral aspect of a process wherein subject and object are inseparable. "Seeing" the photon in this way, the observer would be seeing herself. This merging of observer and observed that is necessary for fully entering the quantum world is reflected in the subtitle of my 2021 paper: "To See a Photon, One Must *Be* a Photon." Here, we would not just have a detached observer viewing objectified quantum states that are superposed. Rather, observer and observed would themselves be superposed.

In my 2021 article, I sought to clarify in specific terms what the conscious experience of quantum superposition might entail by using models found in visual geometry (the Necker cube) and topology (the Klein bottle). I refer the reader to that paper. In the present forum, I will now apply the idea of proprioceptive observation to the phenomenon of photon entanglement.

Entanglement

The 2022 Nobel Prize in physics was awarded to Alain Aspect, John F. Clauser, and Anton Zeilinger for "experiments with entangled photons…[that pioneered] quantum information science" (Royal Swedish Academy of Sciences press release, 2022). The phenomenon of entanglement is closely related to that of superposition. Theorists tell us that, just as different quantum states of the same particle are superposed on one another in the coherent quantum wave ("Schroedinger's cat" is both "alive and dead," in the famous illustration), the quantum states of two different particles can be superposed. The associated particles are then regarded as entangled. "The intrigue of entanglement," says physics writer Lisa Zyga (2015, para. 3), "lies in the fact that the two entangled particles are so intimately correlated that a measurement on one particle instantly affects the other particle, even when separated by a large distance." In effect, the superposed states of entangled particles constitute a single system.

The phenomena of superposition and entanglement play a crucial role in the new quantum technology currently being developed. Here information is processed not in bits with the definite values of 0 or 1, but in quantum bits or qubits, units of information wherein 0 and 1 are superposed. This allows for processing information at speeds far exceeding those of conventional computing. Experimentation with quantum networks has also begun, with an eye toward creating an internet based on quantum principles. The quantum computers associated with this enterprise rely on the entanglement of information that permits it to be transmitted instantaneously between widely separated processors, a procedure known as "quantum teleportation."

In the present paper, I focus on what the phenomenon of entanglement implies for the proprioceptive observation of photons. The phenomenological interpretation of the quantum world described in the foregoing section arrives at the conclusion that "seeing" the photonic wave requires *being* it. In extending this ontological understanding to the question of entanglement, let us bear in mind that entangled photons are, in effect, the *same* photon. My essential proposition then is that proprioceptive observers of entangled photons, in "being" the photons they are observing, would "be" each other. To explore this hypothesis, I am going to propose an experiment in which entangled photons are proprioceptively viewed by remote observers.

Entangled photons can be generated in the laboratory by a process known as Spontaneous Parametric Down-Conversion (SPDC). Here a laser device is employed to send a photon into a crystal (an inorganic compound with crystalline structure) where it can be converted into a pair of entangled photons possessing lower energy. SPDC has been used in many experiments with photons, and Holmes et al. (2018) proposed an entanglement experiment involving human observers. Ordinarily, entanglement research makes use of electronic single-photon detectors. But assuming that the human visual system can detect single photons, Holmes et al. suggested replacing one of the electronic detectors with a human observer as a way of demonstrating that our eyes are sensitive enough to permit us to participate directly in tests of quantum mechanics that confirm the reality of entanglement. Since my own hypothesis is concerned with the relationship between observers of the same pair of entangled photons, photon detection must be left exclusively to the human eye.

The experiment I propose will involve two groups. In the experimental group, participants will be trained to observe photons in the proprioceptive manner that allows them to gain a sense of their own act of observing. The training will make use of Burrow's procedure of "relaxing the eyes and … getting the kinesthetic 'feel' of the tensions in and about the eyes and in the cephalic area generally" (1953, p. 95). Participants in the control group will receive no special training. For these observers, the assumption will be that they are operating in the default posture of viewing the photons transmitted to them simply as objects appearing out in front of them, objects from which they are detached. (Note that the proprioceptive training procedure just described and the procedures outlined below will be further refined in a pilot study once the experiment actually gets underway.)

Observers within each group will be paired off, with the members of each pair being sent to separate dark rooms to make their observations. Similar to an optometrist's method for testing optical functioning, observers will sit before a monitor with their heads steadied in a chin rest and one of their eyes fixed on crosshairs at the center of the screen. On each trial, an entangled photon pair will be created via SPDC and the members of the pair will be sent in different directions to the waiting observers (see Figure 1). The photons will arrive simultaneously at their destinations, having been directed either to the left or right side of each observer's eye, as randomly determined. A forced-choice method will be employed (see Holmes, 2019; Tinsley et al., 2016) requiring the observer to say on each trial whether the photon appears on the right, on the left, or on both sides of her eye, even though photons are never actually sent to both sides.

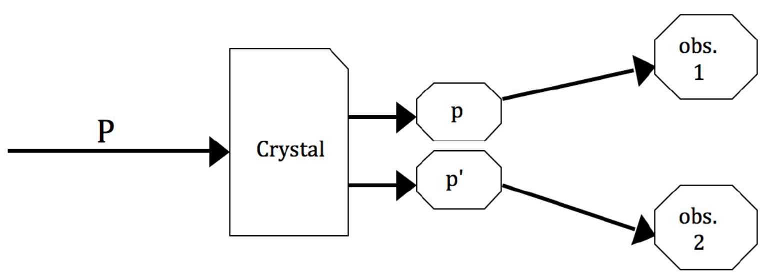

Figure 1: Set-up for observer entanglement experiment. Through the process of Spontaneous Parametric Down-Conversion, a single photon (P) is sent into a crystal and converted into a pair of entangled daughter photons (p and p'), which are then sent to separate observers (obs. 1 and obs. 2).

On the phenomenological interpretation I have offered, the proprioceptive observer is ontologically identified with the photonic wave she is observing: instead of objectifying the photon, she *becomes* it. This leads to the proposition that paired proprioceivers of entangled photons, rather than functioning in a simply independent way, may become ontologically entangled with each other. It would then be possible that such observers, though well separated in space and out of contact with one another in the ordinary sense, could experience each others' optical perspectives as well as their own in viewing their respective photons.

With this in mind, consider a trial in which one photon is sent to the left side of a proprioceiver's eye and the partner photon is sent to the right side of the other proprioceiver's eye (see Figure 1).[2] In cases like this where entangled photons are sent to opposite sides of paired proprioceivers' eyes, the superposition of the proprioceivers' visual perspectives could bring them to choose the response option "both sides," despite the fact that photons have not been sent to both sides of either observer's eye. By contrast, the responses of the observers in the control group should largely be limited to "left" or "right," since these non-proprioceptive viewers would not be ontologically entangled and their observational perspectives therefore would not be superposed. The prediction then is that there will be a significantly greater number of "both" responses in the experimental group than in the control group. This is not to say that there will be no "both" responses at all in the control group. Such responses are far from impossible due to the tenuous nature of single-photon perception.

In the single-photon vision research of Holmes (2016, 2019), Holmes et al. (2018), and Tinsley (2016), photons do not appear to observers as solid, stable presences but are more ghostlike, often showing themselves as ephemeral flashes of light. Consequently, observers might not be entirely sure of the location of the photon they think they have seen and might even believe they have seen photons appearing on both sides of their eyes. As Holmes put it, "it's hard to be sure about such a tiny signal. Noise in the visual system — which can produce phantom flashes even in total darkness — also adds to the confusion" (Holmes, 2019, para. 10). For this reason, research on single-photon perception requires a great many trials in order to establish a statistically significant effect. It seems then that, in the experiment I am proposing, the "both sides" response could well be given in either the experimental group or the control group. Nevertheless, my hypothesis states that a significantly greater number of "both sides" responses will be found in the experimental group due to the superposition of proprioceivers' perspectives in that group.

Castelvecchi (2016) noted a related limitation in experiments on single-photon vision: "more than 90% of photons that enter the front of the eye never even reach a rod cell, because they are absorbed or reflected by other parts of the eye" (para. 7). It is the tenuous nature of single-photon perception in current research and

[2] Note that even though only one eye is used in single-photon research, the binocular convergence response nevertheless occurs, with the unused eye still participating in the optical action (see Chirre, Prieto, and Artal, 2015). The persistence of binocular convergence can be expected, given that this automatic visual process is habitual and is deeply engrained in human physiology, originating in infancy (Horwood, 2018).

the consequent requirement of large numbers of trials to confirm the statistical significance of weak effects that contributes to the wariness of some researchers to conclude that single photons can be seen at all, even though researchers like Holmes have been bullish on the prospect. Physiologist Kerry Kim (2021), for example, notes that while rod cells can *detect* single photons, the light the single photon generates is too weak for human beings to *notice* it (Kim, 2021, "Experiment" section, at 2:54 min.). Perhaps the lack of consensus on this issue is rooted in the subtlety of the distinction between physiological detection and cognitive recognition, a distinction that becomes especially elusive at the lower threshold of perceptual sensitivity. Still and all, while Holmes would agree that inferring single-photon perception from statistical analyses requiring large numbers of trials is far from ideal, she argues that "the data don't lie — if an observer is able to choose left or right with better than 50–50 accuracy and the effect is statistically significant, we know they must have been able to see the light (either that or they're psychic)" (Holmes, 2016, p. 30).

It seems clear that the investigation of observer entanglement I am suggesting would face the same kind of limitation that Holmes has faced. Could anything be done to mitigate the problem? Might it be possible to enhance an observer's perceptual capacity through some form of training that would allow the observer to see single photons more clearly and consistently?

Biophysical anthropologist William Bushell (2016) has addressed this issue. Citing the research of Ericsson, Nandagopal, and Roring (2009) and Ericsson and Simon (1993), Bushell notes: "As Simon and Ericsson and colleagues have conclusively demonstrated, deliberate practice meeting the special criteria of 'expert and exceptional performance' can produce magnitudes of improvement in both qualitative and quantitative measures of performance in many areas, including performance in sensory–perceptual tasks" (2016, p. 33). Among Bushell's primary concerns is the perception of single photons and he observes that past studies of single-photon detection fail to incorporate in their designs methods of extensive training and practice that could bolster photon perception (p. 33). Bushell goes on to discuss certain non-Western meditational practices that seem to significantly augment perceptual acuity. For example, the "specifically stated goal of the Indo–Tibetan yogic tradition is to directly perceive the miniscule, the microscopic, and beyond" (2016, p. 34). Bushell speaks in general "of how intensively trained individuals — adepts or virtuosi of special meditational techniques… appear to be potentially capable of radically enhancing their sensory perceptual capacities to the point of … directly perceiving light at the scale of single photons" (p. 31). However, such attempts at refining micro-perception have yet to be studied in a systematic way and they await further clarification and development. Moreover, for our purposes their relationship to proprioceptive observation would have to be clarified.

Social Implications of Entanglement

Media theorist Marshall McLuhan (1964) made it clear that the introduction of major new media can have profound effects on communication and culture. One illustration he gave is the invention of photography, which he viewed as "decisive in making the break between mere mechanical industrialism and the graphic age of electronic man" (p. 171). McLuhan's analysis included the influence of other new media such as movies, radio, and television. A foremost contemporary example that McLuhan could not have anticipated in his day is the emergent field of quantum informatics. As noted in the previous section, the Nobel Prize-winning research on quantum entanglement has led to breakthroughs in quantum information science that feature quantum computing and the development of a quantum internet in the process of launching a whole new medium.

Much has been written about the social implications of the quantum revolution. The clear consensus is that quantum computing promises to have an immense impact on society. Though the novel medium is still in its infancy and it is hard to know the exact nature of this impact, there is little doubt that quantum computing will bring exponentially faster and significantly more accurate and efficient information processing than is now possible with classical informatics. This, in turn, will result in fundamental changes in the social fabric. According to Hollebeek (2021, para. 1), "The benefits of quantum computing will extend to all aspects of society. Quantum computing will quite literally change the world in various sectors including privacy, finance, health care, entertainment and technology." Expectations of this sort are echoed in a recent article by an expert panel of the Forbes Technology Council (2023), and by Roundy (2023), both of whom enumerate the prospective revolutionary advantages of quantum computing, as well as its challenges. Investment priorities underscore how seriously these possibilities are being taken: "Governments and private entities have invested in both research and development of quantum computing .... The United States passed the National Quantum Initiative Act in 2018 with a budget of more than $1 billion" (Burr, Parakh, and Subramaniam, 2022).

However, while the lives of individuals may be transformed by the quantum revolution, as long as society continues to be based mainly on interactions among separate individuals or exclusionary communities pursuing their separate goals, no bona fide social revolution will have been achieved. What then would it mean for the full impact of the emergent quantum medium to be beneficially felt? I suggest that, in order to fully realize a quantum revolution for society, social relations themselves must be brought to function in a quantum way. Therefore, if my proposed solution of the quantum enigma is correct and the underlying quantum world is essentially a realm of intimate ontological relations (Rosen, 2004, 2008, 2015, 2021), so must be society.

This is a far cry from the way society currently operates, with its alienating zero-sum games and devious manipulations. It is easy to see how the superior speed, accuracy, and efficiency of quantum computing could be used to serve the aims of self-interested exploitation, with disastrous consequences. In the end, the technological breakthrough may actually bring about a societal breakdown. It seems then that to reap the social benefits of the quantum transformation, we must move beyond using quantum technology to serve the self-centered and objectifying way of relating to others dominant in our culture, and employ quantum computing in a manner that would facilitate an ontological entanglement with others.

This is the foremost social implication of the present paper. I proffered above that, by changing one's mode of engaging with the quantum system, by switching from the conventional posture of objectifying the photon to a proprioceptive mode of relating to it, one may counteract the collapse of the photonic wave and participate intimately with the photon, *become* the photon, in keeping with the ontological nature of the underlying quantum reality. And if participants thus engaged interact with photons that are entangled, the participants themselves could become entangled. It is this possibility that would be tested by the outcome of the experiment I have proposed.

Anticipation is high that the small quantum networks of entangled particles now being developed will be expanded to larger networks and, ultimately, to a quantum internet (Metz, 2022). Let us suppose that users of this internet could adopt a proprioceptive posture that allows them to become entangled with each other. Could this not eventually create a kind of social entanglement that could foster a sense of intimacy and ontological linkage? Would such entanglement not fulfill the promise of the quantum revolution to transform society for the better?

I noted above that because quantum technology is still in an early stage of development, we cannot fully know how society will be changed by this new medium. Far less can we know with much clarity what might happen in a society whose social relations would be transformed via proprioceptive quantum engagement. Nevertheless, my reading of quantum science and its social implications tells me that bringing quantum society into its own must entail creating a society that is ontologically interwoven in a quantum manner.

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