# CONCEPTUAL NONLOCALITY

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ABSTRACT: Nonlocality is a puzzling issue in modern physics. I propose that, aside from the experimental determination of nonlocality, the concept of atomistic light—discrete, self-bounded photons—breaks down toward something like nonlocality when subjected to philosophical scrutiny. Louis de Broglie made a similar argument regarding the material atom: the concept of the classical atom, when interrogated, collapses upon itself to offer a glimpse of wave-particle duality. Light atoms or photons, I argue, similarly collapse toward the contradictory possibility of nonlocality.

KEYWORDS: Nonlocality; Photons; Louis de Broglie; EPR; Wave-particle Duality

Up until about 1935 scientists assumed that events impress themselves upon the world in spatiotemporal ways. Events, in other words, do not register or propagate instantaneously; they occur in space and time. Even so-called instantaneous events—a flash of lightning, say—is not instantaneous. It is just very swift, and swiftness makes sense only against a backdrop of space and time.

In 1935 Albert Einstein, Boris Podolsky, and Nathan Rosen (EPR) challenged the Copenhagen interpretation of quantum mechanics by arguing that it implied instantaneous action at a distance.[1] In his reply to this challenge, Niels Bohr stressed the holistic character of the experimental system, which, among other things, incorporates choices made by human agents designing the system.[2] In making particular choices, scientists forgo other choices or possibilities. Measuring a particle's position precisely, for instance, entails not simultaneously measuring its momentum, and one should not (a lá EPR) use unmeasured (but inferred) data to conclude that quantum systems embody more information than can be had experimentally. Our incomplete or probabilistic information about a system, in other words, is fully descriptive of the system, which itself is probabilistic.

By not explicitly countering EPR's point that the Copenhagen interpretation implies

1. A. Einstein, B. Podolsky, N. Rosen: "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?" *Physical Review* 47 (15 May 1935), pp. 777-780.

2. Niels Bohr, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 48 (15 October 1935), pp. 696-702.

instantaneous action at a distance, Bohr left the possibility open. One might infer such action from Bohr's emphasis on the overall unity of the experimental set-up where certain parts of a system remain mutually intact even while moving apart.[3] This outlook, owing to later experimental tests designed to decide the issue, now appears correct. It seems that different parts of a system, though not collocated, may, in some circumstances, interconnect or "hang together" instantaneously. Here the word *parts* refers to photons, electrons, and other quantum entities. They may be locally situated but, in some circumstances, their effects, or the measurement effects impressed upon them, are nonlocal—that is, immediately felt or registered elsewhere.

This, of course, is puzzling, but there are many puzzling aspects of modern physics. My intent is to show that the *concept* of atomistic light—self-contained, pellet-like photons—prompts the inference of nonlocality. Put differently, the idea of atomistic light implodes toward nonlocality when subjected to philosophical scrutiny. One response to the puzzle of nonlocality, then, entails interrogation of the categories we use to frame the puzzle. First, however, a brief description of nonlocality.

## NONLOCALITY

Robert Nadeau and Menas Kafatos define locality as the assumption that "signals or energy transfers between space-like regions cannot occur at speeds greater than light."[4] Here "space-like" means that events are so situated as to preclude connection by a light signal: a photon generated at event A will still be moving toward event B when B occurs. Given this and our understanding that signals propagate no faster than light speed, one might justly conclude that two such events cannot instantaneously affect each other. The experimental determination to the contrary—that such effects do occur—is known as nonlocality.

Nadeau and Kafatos argue that nonlocality teaches us that the universe is more than the sum of its parts. We can sometimes, of course, profitably regard it as a mere aggregation of parts, those parts being its primary constituents, but this outlook is complementary to the thesis that, in some sense, the cosmos is a seamless whole. Neither stance exhausts the reality we know, and no part-hood ontology (one that privileges parts as ultimate ground) can adequately deal with nonlocality. At some level, then, the whole exists "within all the parts (quanta),"[5] the universe being something like its own

3. As others have noted, Bohr's language is obscure. Stating that the measurement of one particle will cause no instantaneous "mechanical disturbance" of another, distant particle, he nevertheless insists that "at this stage [the measurement of the first particle] there is essentially the question of *an influence on the very conditions which define the possible types of predictions regarding the future behavior of the system*." (Bohr, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", p. 700; emphasis in the original.) Arthur Fine characterizes this wording as a retreat into positivism and a shift from "actual physical disturbance" to "semantic disturbance." Arthur Fine, *The Shaky Game: Einstein Realism and the Quantum Theory*, 2nd ed. (Chicago, IL: University of Chicago Press, 1996), pp. 34-35.

4. Robert Nadeau and Menas Kafatos, *The Non-Local Universe: The New Physics and Matters of the Mind* (Oxford, UK: Oxford University Press, 1999), p. 69.

5. Nadeau and Kafatos, *The Non-Local Universe*, p. 197.

fundamental constituent. Nonlocality, say Nadeau and Kafatos, discloses this level, the mutual immanence of part and whole.

This assessment, of course, goes beyond nonlocality proper—it is an interpretation thereof. And while it is surprising in its claims, those claims are no less surprising or counterintuitive than nonlocality itself. Hence it is difficult to assess nonlocality without reaching for unfamiliar imagery. After stating that experimental evidence of nonlocality teaches us that "two particles [otherwise thought to be spatially separated] are tangled together into a seamless unity," George Greenstein and Arthur Zajonc go on to remark that

> Hidden behind the discrete and independent objects of the sense world is an entangled world, in which the simple notions of identity and locality no longer apply. We may not notice the intimate relationships common to that level of existence, but, regardless of our blindness to them, they persist. Events that appear to us as random may, in fact, be correlated with other events occurring elsewhere. Behind the indifference of the macroscopic world, "passion at a distance" knits everything together.[6]

The phrase "passion at a distance," attributed to Abner Shimony, is used here in direct response to "action at a distance," which historically has denoted the propagation of signals and causal effects. Such are not propagated via nonlocality, and so it (passion at a distance) does not entail a violation of Einstein's postulate that information or causal influences can't travel faster than light speed. What it does entail is a certain passiveness or even helplessness in the face of pre-existing unity or togetherness. No one can manipulate the individual parts of an EPR system (an experimental setup that affirms nonlocality, say) to timelessly transfer information or causal effects. What happens at my end of the system happens before I can take charge of the situation to communicate a signal to your end of the system. In other words, I am not outside the system manipulating its switches and levers. Nonlocality thus prompts the suggestion that ultimately there is no outside—those who witness nonlocality have already been brought into its indissoluble unity.

While nonlocality breaks the frame of everyday thought, I believe it is implicit in the concept of atomistic light. Decades ago Louis de Broglie made a similar claim about the concept of atomistic matter. That idea, he insisted, opens out onto wave-particle duality. We turn now to de Broglie's argument.

## ATOMISTIC MATTER

Another so-called quantum puzzle is wave-particle duality.[7] Having long regarded

6. Geroge Greenstein and Arthur Zajonc, *The Quantum Challenge: Modern Research on the Foundations of Quantum Mechanics*, 2nd ed. (Boston, MA: Jones and Bartlett Publishers, 2006), p. 184.

7. Richard Feynman introduces the double-slit experiment—an experiment which throws wave-particle duality into stark relief—by portraying its outcome as "a phenomenon which is impossible, *absolutely* impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery. . . . the basic peculiarities of all quantum mechanics." Richard Feynman, *The*

waves and particles as mutually exclusive phenomena, physicists in the early decades of the twentieth century struggled to blend them together. Now we accept that interblending without feeling a need to fully understand or explain it. But according to de Broglie, one of the architects of wave-particle duality, the classical concept of the atom, when scrutinized, breaks down in such a way as to afford a glimpse of that duality. Referring to the ancient debate over the nature of physical matter—whether it is finitely divisible (atomistic or discontinuous) or infinitely divisible (continuous)—de Broglie states:

> Reality cannot be interpreted in terms of continuity alone: within continuity we must distinguish certain individual entities [atoms or quanta]. But these individual entities do not conform to the idea which pure discontinuity would give us of them: they have extension, they are continually reacting on each other and, a still more surprising fact, it appears to be impossible to localize them and define them dynamically with perfect exactness at each instant. This conception of individual entities, rather vaguely outlined against the background of continuity, is something entirely novel for physicists, and seems to be a slightly shocking suggestion to some of them. Yet surely it harmonizes with the conception to which philosophical considerations might lead.[8]

The ancient atomists neatly separated discontinuity off from continuity by situating indivisible particles in a void whose very nothingness offered no resistance to the prospect of continuity or infinite divisibility. But in modern physics, this dichotomy cannot be sustained because particles sometimes behave as if they were continuous or wave-like. As de Broglie suggests, this blurring of categories, while surely the result of scientific discovery, is nonetheless a consequence of imprecise thought, for the concept of a discontinuous particle is pregnant with philosophical conundrums that erode the distinction between continuity and discontinuity.

In de Broglie's mind, the primary conundrum is this: if atoms are indivisible and have spatial magnitude (as they were anciently conceived), it would seem that their inner structure must be homogenous or continuous throughout. But then continuity becomes descriptive of fundamental reality and we are faced with the task of explaining why the inwardly continuous atom can't be subdivided. Why is there continuous matter for parts but no parts? What is more, should parts be found—should the atom be found to be not fundamental—what then? Then, says de Broglie, we encounter a "vicious infinite, since the new elementary particles of which the original particle, now seen to have been falsely so called, is supposed to be formed, will be faced with the same questions and the same difficulties."[9]

Let us try to pose the argument more rigorously. Either physical matter is continuous or discontinuous. By assuming that it is discontinuous we end up with atoms, indivisible bits of matter. But atoms take up space, which implies that their atomistic surface

*Feynman Lectures on Physics*, vol. 1 (Reading, MA: Addison-Wesley Publishing Corporation, 1989), p. 37-2. Emphasis in the original.

8. Louis de Broglie, *Matter and Light: The New Physics*, trans. W.H. Johnston (New York: Dover, 1946), p. 231.

9. De Broglie, *Matter and Light*, p. 219.

bounds either (1) continuous matter or (2) discontinuous matter. If it bounds (1), the atom cannot be said to be fully atomistic, for its inner structure is continuous. If it bounds (2), the atom is not atomistic at all, for its inner structure is discontinuous, and we are now faced with an infinite regress of discontinuities, which is exactly what continuity entails. In either case, the classical atom implodes upon itself toward continuity.

Had physicists, by probing the *idea* of the atom, discovered this conceptual breakdown, they would have been less surprised by the emergence of wave-particle duality—this is de Broglie's broader point. In what follows I probe the idea of atomistic light hoping to show that this idea similarly breaks down toward a contradictory possibility.

## ATOMISTIC LIGHT

People often explain wave-particle duality by saying that, depending on circumstance, light manifests itself either as a wave or as a particle. While this explanation may be a good first approximation, it is also misleading in that it preserves the idea of atomistic light; that is, indivisible, self-contained photons. Thinking in this register, we imagine discrete bits or pellets of light moving through space.[10]

One problem with this picture is that it cannot, even in principle, be empirically witnessed. Even if our eyes were sensitive enough to detect a single photon, how would they see a photon in intermediate space? There are two interlocking considerations here, the first going back at least to Plato and the second more recent.

The first consideration entails the stance that light is a principle of seeing, not something to be seen. It is for Plato what we see *by* and is therefore not fully commensurate with visible reality.[11] Saint Augustine understood light similarly, and modern thinkers, less inclined to think about light's religious or mystical possibilities, have straightforwardly asserted that light is not an object of vision but the invisible means by which vision is accomplished.[12] One gets a sense of this by noting that light shone into the night sky does not visually announce itself, just as a movie projector beam is not seen above one's head in a theater. Illuminated raindrops or dust particles may be seen, but that is light in conjunction with something material, not light *per se*. Another example is the sun seen from the moon. It is a material ball of light against the blackness of outer space; it does not visibly radiate light because the moon has no atmosphere to scatter light.

10. For caveats against this attitude see Rodney Loudon, *The Quantum Theory of Light*, 3rd ed. (Oxford: Oxford University Press, 2000), p. 1; Greenstein and Zajonc, *The Quantum Challenge*, pp. 36-37.

11. Plato, *The Republic*, bk 6, trans. Benjamin Jowett (New York: Vintage, 1991), pp. 246-253.

12. Jonathan Powers writes: "When we see an object we see patches of colour, of light and shade. We do not see a luminescent stream flooding into our eyes. The 'light' we postulate to account for the way we see 'external objects' is not given in experience; it is inferred from it." (*Philosophy and the New Physics* (London: Methuen, 1982), p. 4) P.W. Bridgman's comment is also apropos: "The most elementary examination of what light means in terms of direct experience shows that we never experience light itself, but our experience deals only with things lighted. This fundamental fact is never modified by the most complicated or refined physical experiments that have ever been devised." (*The Logic of Modern Physics* (New York: Macmillan, 1955), p. 151) Other such statements from a broad range of thinkers could be offered, but I hope these will suffice to make the general point.

The second consideration involves John Schumacher observation that "nothing, not even light itself, can bring us news of its upcoming arrival; it brings us news of its arrival only by arriving itself."[13] We do not, in other words, see light in intermediate space: light is its own messenger, and for this reason, Schumacher argues, it occupies "a unique place in our experience."[14] That uniqueness, he continues, entails (among other things) light's ability to completely "drop out of experience" while effecting visual experience of distant objects.[15] Let us consider how this occurs. That is, let us, with Plato and Schumacher in mind, review the standard account of photon-mediated vision.

Upon impinging on the eye, light announces things like trees and buildings—things physically remote from the eye. At least this is what we typically imagine: image-bearing photons impacting locally, as it were, on the retina to effect immediate visual experience of distant events. What is interesting about this account is that the posited but not experienced local event—we do not see photons per se striking the eye—is simultaneous with a visual experience of something distant. In one stroke, photons exchange or give up their local presence—their contact with the retina—for the visual presence of distant objects. Physically absent or at least distant, those objects are perceptually present, while photons, said to be physically present, are perceptually absent.

Summing up these two considerations we may say that (1) photons per se are imageless or invisible and (2) photons are their own messengers, although they don't announce themselves but other things. If both these claims are true, then it becomes hard to imagine how two counter-propagating photons could interact across space and time as we might expect them to in EPR-type situations. That is, it is hard to imagine how such interaction, should it occur, could be anything but spaceless and timeless. Given (1), photons would have no images to facilitate the interaction across space and time owing to light's innate invisibility or imagelessness (Plato's point); there would be nothing to signal with. Furthermore, given (2), the photons themselves would have to act as their own messengers (Schumacher's point), which would seem to imply collocation rather than interaction bridging two separate locations.

The salient point is that when we consider what they can and cannot be *visually*, photons lack the resources with which to interact across space and time; by their very nature they must interact at the same place—that is, instantaneously. Granted, this does not make much sense, but neither does nonlocality as it is spelled out by modern physics. But perhaps the concept of atomistic light (discrete, self-bounded photons) is at the bottom of this puzzle. When we probe that concept, it offers us a glimpse of nonlocality, just as the concept of the material atom, when probed, offers us a glimpse of wave-particle duality.

13.John A. Schumacher, *Human Posture: The Nature of Inquiry* (Albany, NY: SUNY Press, 1989), pp. 113-114.

14. Schumacher, *Human Posture*, p. 114.

15. Schumacher, *Human Posture*, p. 114.

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