A RESPONSE TO CARL HELRICH: THE LIMITATIONS AND PROMISE OF QUANTUM THEORY

by Lothar Schäfer

Abstract. I respond to Carl Helrich's criticism of my proposition that the emergence of complex order in the universe is from Virtual State Actualization (VSA). The question is discussed as to whether quantum theory is able to afford any kind of quantum ontology or whether it merely allows an epistemological view. I point out that, even though many contradictory interpretations of quantum theory are currently possible, the concept of VSA is based on molecular properties that are so simple and factual that they are beyond interpretation. Helrich's appeal for caution in proceeding from physical reality to Divine Reality is wholeheartedly supported and a detailed discussion is given.

Keywords: electron diffraction; emergence of complex order; immanent order; quantum ontology; quantum perspective of evolution; quantum state transitions; transcendent order; virtual state actualization; wave functions.

The Question of the Meaning of the Wave Functions

In his response to my essay (Schäfer 2006), Carl Helrich addresses the important question of the meaning of Schrödinger's wave functions ψ. In this context he remarks, "[Max] Born pointed out that, although the wave function itself has no physical meaning, the square of the modulus of the wave function is the probability density function for the spatial location of the quantum system" (Helrich 2006, 554). My own position—"Schäfer seems to accept the wave function as a reality" (Helrich 2006, 562)—seems falsified by the fact that the calculation of quantum numbers can be "carried

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out based on symmetries of the Hamiltonian operator; no actual representation of the state vector as a wave function is ever needed" (p. 562). Furthermore, the difficulty in considering ψ as an actual physical quantity lies in "the complex valued property of the wave function and the fact that the wave function is spread out over a region of space. Measurements of electrons in diffraction experiments, for example, provided single spots on photographic films, which resulted from impacts of single electrons with atoms making up the film. The results were not smeared out over regions of the film" (p. 554).

From this collection of remarks representing Helrich's critique, I summarize the following points: (1) Assigning any sort of reality to ψ contradicts historic authority. (2) The mathematical machinery of quantum theory has no need for ψ as a wave function. (3) Particles observed are localized, but the ψ are extended in space. (4) Particles are real, but the ψ contain imaginary numbers.

I am very grateful for Helrich's remarks, because they bring out the need to specify precisely on what basis a given metaphysical stance is assumed. First of all, my position is based not so much on a specific form of quantum theory and its technical operations but, as far as possible, on the quantum phenomena. Thus, I am not assuming that the creatures of a specific theory—Schrödinger's wave functions ψ—are real, but the wavelike aspects of quantum entities are real because they are suggested by empirical observations. It is physical experience that leads me to believe that the mathematical properties of ψ have a correspondence in objectively existing properties of the quantum entities and that ψ represents more than our knowledge of a system. The theory may be obsolete tomorrow. The phenomena will probably remain as counterintuitive as they are now.

It is in the quantum phenomena and not in specific mathematical operations that classically unexpected wavelike aspects of nature come to the fore. Such phenomena emerge, for example, in single-particle interference experiments. Louis-Victor De Broglie's relation, $\lambda = h/p$, assigns both a wavelength, λ, and a particle property, p, to a quantum entity. It is not possible to select one aspect as real and at the same time reject the other one as an artifact of theory. That same parameter, λ, occurs in Schrödinger's wave function for a free particle, ψ. That it should appear in conjunction with imaginary numbers does not have to mean that "ψ has no physical meaning," but it can be related to the dual structure of reality: I note with H.-J. Fischbeck (2005, 20) that complex numbers are common in describing the realm of potentiality in physical reality.

Electron diffraction is a powerful tool of structural chemistry. I have spent most of my professional career applying and improving that method. In electron-diffraction experiments electrons are emitted from a heated filament into the free space of an evacuated environment, and a sharply focused electron beam is formed by accelerating the emitted electrons through a selected voltage. In these experiments the wavelength, λ, is an important parameter of data analysis (see, for example, Schäfer 1976; Ischenko, Ewbank, and Schäfer 1994) and is generally referred to as *the wavelength of the electrons*, implying that λ is an objective property of an objective quantum entity. That property can be manipulated at will by changing the accelerating voltage; in a predictable and testable way higher voltage leads to shorter wavelengths, and vice versa. For someone who has been in contact with this method for a long time and in a practical way, it is difficult to accept that the wave aspects of quantum particles do not correspond to an objective property of the physical reality.

As to the conflict between the localized nature of quantum particles and the property of ψ to be extended in space, we note that the property of space extension is a characteristic aspect of single-particle interference phenomena. This is because the classically conceivable but indistinguishable possibilities of a quantum object to obtain the same observable result, which form the basis of these interference phenomena, typically involve extended regions in space or time. Similarly, the entangled states of two quantum objects that are used in experiments to test Bell's inequality give rise to phenomena that are physically spread out in space or time, thus indicating the existence of objective entities that are spread out in space or time. That the nonlocal effects in Bell-type experiments may be explicable by assuming that the unobserved entangled states exist outside of space-time (Stapp 1977; Kafatos and Nadeau 1990; Goswami et al. 1993; Nesteruk 2000) does not remove them from the realm of ontology.

As to the power of authority, when Helrich can quote Max Born for the metaphysical stance that "the wavefunction itself has no physical meaning" (p. 554), Werner Heisenberg ([1958] 1962) can be quoted for the opposite metaphysical stance. Henry Stapp has given a particularly clear description of Heisenberg's interpretation of quantum reality:

> The wavelike aspects are interpreted in the Heisenberg ontology . . . not as subjectively defined probabilities pertaining to our experiences of results of measurements, as in the strictly orthodox Copenhagen interpretation of Bohr. They are interpreted, rather, as "objective tendencies" for certain "actual events" to occur. These "actual events" correspond to the particlelike aspects of nature. (Stapp 1993, 124)

Clearly, this identifies wavelike states as objective ontological entities of physical reality.

That interpretation of quantum theory is further supported by Stapp when he writes:

> In Heisenberg's picture, which is the one informally adopted by most practicing quantum physicists, the classical world of material particles . . . is replaced by the Heisenberg state of the universe. This state can be pictured as a complicated wave, which . . . represents not the actual physical universe itself, in the normal sense, but merely a set of "objective tendencies", or "propensities", connected to an impending *actual event*. (1993, 148)

In this way one introduces a possible "quantum *ontology*, departing from the purely epistemological stance of the strictly orthodox Copenhagen interpretation" (1993, 149).

Turning to Heisenberg directly:

> The concept of the probability wave was something entirely new in theoretical physics since Newton. Probability in mathematics or in statistical mechanics means a statement about our degree of knowledge of the actual situation. In throwing dice we do not know the fine details of the motion of our hands which determine the fall of the dice and therefore we say that the probability for throwing a special number is just one in six. The probability wave of Bohr, Kramers, Slater, however, meant more than that; it meant a tendency for something. It was a quantitative version of the old concept of "potentia" in Aristotelian philosophy. It introduced something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality. (Heisenberg [1958] 1962, 40)

Clearly, this makes the entity represented by the probability wave, even the probability wave itself, an objective ontological—*real*—entity. The same is expressed in the statement "The transition from the 'possible' to the 'actual' takes place during the act of observation . . . as soon as the interaction of the object with the measuring device, and thereby with the rest of the world, has come into play; it is not connected with the act of registration of the result by the mind of the observer" ([1958] 1962, 54).

The current situation in quantum physics is characterized by the fact that many interpretations of quantum theory are possible, not only the one offered by Born. Helrich is correct in his assessment that Heisenberg's interpretation is my preferred interpretation. It is possible to think that a frontier is passed in measurements between the mindlike (the virtual or potential) and the matterlike (the actual). The first step in converting the mindlike into the matterlike lies in the conversion of a virtual wavelike state into an actual wavelike state. At this frontier the conversion is achieved, because nothing is involved other than turning one logical structure into another logical structure.

The Question of the Consistency with Contemporary Physics

One of the most serious criticisms made by Helrich is his claim that some of my views are inconsistent with theoretical physics. "I have pointed to the inconsistencies of some of Schäfer's ideas with present theoretical physics" (Helrich 2006, 564). In view of the fireworks of technical details that he offers to pass this judgment, it is necessary to recall the premises underlying my main hypothesis—that is, the proposition that the emergence of complex order in the universe is by virtual state actualization (VSA).

The main premises of VSA are that (1) atoms and molecules exist in quantum states; (2) changes in material systems are connected with changes of states; (3) state transitions are possible only when a system has access to empty (virtual) states; and (4) the properties of the empty states of a system are predetermined by its constitution—that is, forming a realm of potentia, virtual states exist in a logical, mathematical, and potential way that can be predicted a priori before they are actualized. These aspects of material systems are all that I need for my hypotheses, and I state emphatically that they are not in any way "inconsistent with present theoretical physics." In contrast, some of the essential claims by Darwinians *are* inconsistent with our current understanding of atoms and molecules. Specifically, the claim is untenable that the emergence of complex order in material systems is from jumps out of *nothing* and that the new and emerging order is *created* by chance in an arbitrary way. This point is not insignificant. When the emergence of complex order is by VSA, there are limitations as to what kinds of forms are possible, because the emerging forms are connected with quantum states whose properties do not vary continuously and arbitrarily from one state to another, and they emerge from an order that exists in the potential realm of reality before it becomes an actual order.

In this context it does not matter which one of several available procedures we apply to calculate the properties of quantum states. It does not matter whether we talk about "wave functions" or "state vectors," avoiding "any direct use of the wave functions" (Helrich 2006, 561). The only thing that matters is that there are actual states—occupied—and virtual states—not occupied—and their properties can be somehow calculated a priori. In my language I have chosen wave functions to describe my views, because the only practically applicable procedures of current quantum chemistry that can be used to calculate the properties of sizeable molecules are based on Schrödinger's formalism, and wave functions are an essential term. It is interesting that Helrich takes me to task for giving virtual states too much reality (as on p. 563, when he writes: "physics attributes no meaning to the existence of molecular quantum states before interactions are present"), while I am reprimanded by Ervin Laszlo for not granting virtual states enough of that precious commodity, reality.

Helrich rejects the notion that the realm of potentiality represents a transcendent order. "Schäfer proposes a conception of virtual quantum states as transcendent reality. . . . I fail to see unoccupied states as evidence of transcendence" (p. 562). I repeat my motivation: I have called the order of virtual states *immanent*, because it is part of the constitution of actual systems. I have called it *transcendent*, because the realm of potentiality transcends the realm of matter and transcends the realm of our direct experience. Give me a better word that describes, in short, the *essential* difference between the thinglike objects of the actual realm of reality and the logical objects of the realm of potentia, and I will use it. It is true that unoccupied quantum states result mathematically "from whatever interactions we use to write the Hamiltonian" (p. 563). But it is also true that the states obtained in this way *have the potential* of becoming actual states exactly with their mathematically predicted properties. Thus they are more than simple mathematical formulae, and it is possible to accept them as Heisenberg entities that exist "between the idea of a thing and a real thing." As it seems, my use of the term *transcendent* is not far off the usual understanding of that term, which the Encyclopedia Britannica, for example, gives as "extending or lying beyond the limits of ordinary experience."

There is no doubt that the challenges of language are considerable here, and they are reflected by Helrich's own presentation. For example, I note a subtle contrast in his statement "These probability densities are no more physically real than the wave function, from which they are obtained" (p. 562) and the statement "Born pointed out that, although the wave function itself has no physical meaning, the square of the modulus of the wave function is the probability density function for the spatial location of the quantum system" (p. 554).

Helrich argues against the notion of transcendence in unoccupied states by pointing out that "We also cannot decide by any measurement which state is occupied and which is not. All we can measure is the result of a transition" (p. 563). Similarly, "Even the actual measurement of an electron in orbit is beyond physical possibility" (p. 562). Truly, this is a very serious argument, because, if occupied states have no effects distinguishable from empty states, the distinction between them seems irrelevant. However, the case is not as simple as that.

First of all, occupied states give rise to an *observable* probability density; unoccupied states do not. That sets the former apart from the latter. Second, even though *we* cannot measure which atomic or molecular state is occupied and which is not, *atoms* can very well "measure" the states of other atoms and the orbital properties of their electrons, and they do so in a way *observable to us* when a chemical bond is formed. When the wave-like states of a group of atoms interact with each other and a molecule is formed, the result depends significantly on which states in the participating atoms are empty, which are occupied, and what the precise properties of the electrons are in specific states. For example, if the orbital occupancy is such that p-orbitals must be involved in forming a molecule, a molecule will arise with chemical and physical properties—*observable* properties—completely different from the systems obtained when only s-orbitals or d-orbitals are involved in forming a chemical bond. A vast number of examples are described in chemical textbooks that show that the chemical properties of molecules are related in an observable way to the shapes of orbitals like those shown in my Figure 1 (Schäfer 2006, 511), and these properties cannot currently be rationalized in any other way. This of course does not mean that electrons are smeared out in space, as Helrich correctly states. It means that, while we may not be able to observe directly the occupancy of quantum states, we can do so indirectly by letting the atoms do the job and by inspecting the results of atomic interactions—that is, by studying the properties of molecules.

I return to Helrich's statement "All we can measure is the result of a transition" (p. 563). The fact of transitions is all we need for the model of VSA, because spectroscopic transitions imply that there are occupied states and empty states. In molecular spectroscopy, specifically, the Franck-Condon principle states that, among the many states that are available for a given vibronic transition, those will most likely be selected—that is, the observed transition will be most intense—for which the wave functions of the actual and virtual states have the greatest overlap integral. In this process the precise forms of the state functions come into play, further establishing an indirect means of testing a priori calculated properties of specific states.

The atomic orbitals of my Figure 1 were merely used as a convenient example to illustrate that quantum entities can be thought to be connected with virtual forms. The selection does not mean that virtuality (potentiality) is a property only of electronic states. Rather, it is a property of all the states of material systems that our current description forces us to separate into different types: vibrational, space-rotational, intramolecular-torsional, and the states connected with the potential hypersurfaces of atom groups, which can form different chemical species by populating stable states. In each case changes of material systems are possible only because there are empty states. This requirement holds regardless of what state a system is in and regardless of whether or not we can know which one of a system's states is occupied and which ones are empty.

Many physicists now accept the view that quantum theory applies not only to the microscopic realm but to all of reality (see, for example, Stapp 1993, 123; Fischbeck 2005, 19). Adopting this view, I accept the observed conditions of molecules as a model for all of reality. From the molecular conditions it is possible to infer that all of reality consists of a potential realm whose logical order is prior to an actual realm. Adding to this the aspect of the wholeness of reality, it is possible to think that all virtual states are cosmic states, leading to the quantum-ontological postulate described above.

Does my response to Helrich's criticism mean that I brush *his* remarks from the table, claiming that they are irrelevant? Absolutely not! When a deeply thoughtful and sincere expert such as Helrich is prompted to make the kind of comments that he makes, it is a sign that the presentation needs some improvement, which I hope I have done with this response. As is the case with the other responders, I am immensely grateful for Helrich's efforts and for the additional thoughts that he has entered into the discussion. We should also not overlook agreement on many essential points. For example, I could not have said in a more gripping way than Helrich does on p. 564: "I do think that in the quantum theory we are encountering something that potentially may be far more revealing of the depths of the universe than we presently recognize. I also believe that the investigations of consciousness will bring us into contact with something more."

The Question of Caution in Relating Science and Religion

I wholeheartedly support Helrich's appeal for caution in proceeding from physical reality to Divine Reality, and I applaud his position of modesty: "I am primarily a physicist and believe that my greatest contributions to the dialogue between religion and science can be realized if I remain in the position of a scientist. . . . I do not consider myself competent to engage in the development of theological concepts" (Helrich 2006, 560–61).

In defense of my own thoughts, they are reactions to the quantum phenomena that I have as a human being and not as a scientist who is trying to dictate wisdom to theologians or anyone. In this I take seriously the personal remark of a friend and distinguished theologian, John Granger Cook (2000; 2004), that there is a danger in this science-theology dialogue of forming an image of God after the image of man. At the same time I cannot help but think that, if God is in the world, changes in our understanding of the world must lead to changes in our understanding of God. Here I rely on the theological authority of H. Küng when he suggests that the biblical message itself has "to be detached from its time-conditioned ideological framework and repeatedly translated for each new age" (1980, 117).

It is inspiring to find parallels between *possible* aspects of quantum reality and basic thoughts expressed in the grand philosophical systems of our history. Heisenberg was the first to seek out such parallels in Greek philosophy; Wolfgang Pauli, Erwin Schrödinger, Niels Bohr, and others were aware of similarities with Eastern mysticism, more recently described in great detail by Fritjof Capra (1991). Considering such parallels is simply a source of joy.

I agree with Kant (and Helrich) that our knowledge extends as far as our experience. However, beyond the realm of knowledge, thoughts are possible that are neither meaningless nor illegitimate. Personal thoughts about God, in particular, need the freedom of the mind.

Trying to find signs of a divine reality in physical reality does not mean that God is considered a problem that needs to be solved, as in Paul Tillich's remark quoted by Helrich (p. 552). But I think that searching for divine reality is an overriding need in human life, one that is shared by atheists who simply react in a different way to it.

Küng describes the despair of Pascal in facing the mechanical universe: "Pascal took very seriously man's forlornness in the infinitely impermeable universe, out of which no Creator's voice can be heard: 'The eternal silence of these infinite spaces fills me with dread . . . I see the terrifying spaces of the universe hemming me in'" (Küng 1980, 52, 54).

The quantum phenomena have shown that there is no need for despair or the feeling of being hemmed in. If the nature of reality is that of a wholeness, we are a part of it. If the background of reality is mindlike, it will think in us.

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