EXPERIMENTAL LIFE: HEELAN ON QUANTUM MECHANICS

"Measurement is not an impersonal event that occurs with impartial universality," says Niels Bohr in Michael Frayn's Tony-award winning play Copenhagen. "It's a human act, carried out from a specific point of view in time and space, from the one particular viewpoint of a possible observer."¹

Patrick Heelan has spent most of his career addressing and elaborating the philosophical implications of just this issue. His route to it began while studying math and theoretical physics in the course of earning his BA and MA at University College, Dublin (1947-8) during which time he worked with Erwin Schrödinger at the Dublin Institute for Advanced Studies (1948-9). Heelan earned a Ph.D. (1952) in geophysics at St. Louis University, returned to the Dublin Institute for Advanced Studies (1953-4), studied theology during his Jesuit training (1954-60) and then went to Princeton on a Fulbright award to work as a postdoctoral student with Eugene Wigner (1960-2). At Princeton his attention was first seriously drawn to the philosophical issues raised by quantum mechanics. For while he had no difficulty understanding or using the theory of quantum mechanics, which worked quite effectively in the laboratory, he found that he had trouble understanding the way Princeton physicists spoke about it. He was puzzled by the disparity between the clarity and correctness of the theory and the obscurity and inaccuracy of the language used to speak about it.

This disparity seemed to have arisen at the very beginning when quantum mechanics had been formulated by its progenitors, particularly Niels Bohr and Werner Heisenberg in the 1920s and 1930s, as a theory of the microscopic domain to complement the Newtonian theory of the macroscopic domain. But the disparity had continued and even been exacerbated when John von Neumann, Eugene Wigner, and others had reformulated it in the 1940s and 1950s, as a universal physics to replace Newtonian physics and become a theory for all realms.

The way Bohr had spoken about quantum mechanics was essentially Kantian: Human beings are endowed with the ability to think and imagine according to certain (classical) categories and schemata. These categories and schemata are adequate for macroscopic events and are appropriate for the classical physics which sought to provide the theory for such events. The pioneers of the quantum realm, however, had discovered that these categories and schemata do not apply to microscopic events. This is most evident in connection with the Schrödinger wave equation, which depicts a particle as a "packet" or superposition of possible states without a definite position,

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momentum, energy, and so on; when that packet is measured – by a macroscopic (nonquantum) object, the instrument – the wave packet "collapses," and all but one possibility is excluded by random anonymous choice. But we cannot get around the classical schemata in our thinking and imagining. Therefore, concluded Bohr, in our thinking about the microscopic world we are forced to depend on classical categories and schemata – such as position and momentum – but these categories are to be used in nonclassical ways, as in "complementary" pairs. One therefore had to give up the notion that the concepts and schemata adequate for sensible phenomena in the macroscopic world corresponded to what was "really real" in the microworld. This Kantian approach therefore severs any ontological connection between the quantum theory and the world of "real" phenomena. "[A]n independent reality in the ordinary physical sense can neither be ascribed to the phenomena nor to the agencies of observations," wrote Bohr.² Physicist Frank Wilczek has aptly characterized this Copenhagen strategy as a "renunciation."³

But if Heelan found that unsatisfactory, he found the way of the Princeton reformulators of quantum mechanics – von Neumann and Wigner – more unsatisfactory still. Whereas Bohr and Heisenberg had treated the act of measurement as involving the interaction of a quantum object and a classical object and viewed that interaction as sufficient to collapse the wave function, von Neumann and Wigner, in universalizing quantum mechanics – treating both the object measured and the measuring instrument as quantum objects – introduced a new and more challenging problem: how does a single complex wave function of object and instrument get reduced to a single eigen function and one value in the course of measurement? Von Neumann and Wigner thought that the answer had to lie in another kind of interaction, one involving the human element: they took the reduction of the new, enlarged wave packet to be proof that the real world is not entirely materialistic. The human mind changed the state of the object being measured, and therefore quantum phenomena testified to the ineradicable presence of mind or soul in the world.⁴

Both of these ways appeared to undermine the Western view that objectivity belongs to those things whose fundamental properties – in principle at least – are independent of the human realm and can all be specified at every instant and in every place, with the corollary that what the measurement process does is to sample a pre-existing ideal value. This view is oriented by the image of a divine demiurge able to intuit the world's already present and fixed essences. In challenging this view, these articulations of the nature of quantum mechanics appear to give credence to the claim of undermining objectivity – feeding skepticism, New Agey views about the illusory nature of reality, and superficial parallels to Eastern mysticism.⁵ However, Heelan sensed in Heisenberg's writings a dissatisfaction with the Copenhagen view – even though Heisenberg himself overtly agreed with it and had contributed to its formulation – and also sensed that this dissatisfaction could be articulated with the aid of certain approaches taken by continental philosophers. Heelan would write, "[T]he modern European continental philosopher feels closer to him in spirit than does, perhaps, his Anglo-American counterpart."⁶

When Heelan left Princeton he went to the University of Louvain in Belgium to work on a dissertation on Heisenberg's philosophy of science, and simultaneously began an intensive study of continental philosophy, especially the works of Husserl, Heidegger, and Merleau-Ponty. Heelan learned that Heisenberg's first understanding of quantum mechanics had differed sharply from Bohr's: initially, Heisenberg had thought that the right approach was to change the meaning of words like "position" and "momentum" - to give them nonclassical meanings - while Bohr wanted to keep their (classical) meanings, admit that they were irretrievably classical, and change the way they were used. Heisenberg's approach resembled Einstein's approach to relativity in his paper of 1905. Whereas Einstein aimed to redefine "time" in his theory of simultaneity by claiming that real simultaneity was what was observable in a real situation, so Heisenberg set out to redefine position and momentum in his matrix mechanics – which stated the suite of possible values that a quantity could have and said something about their mutual relationship - by claiming that real position was what was observable in a real measurement, when only one of these possibilities would appear. This approach (which involved rejecting Schrödinger's wave mechanics) finally crystallized on that famous stay on Helgoland in 1925, during which Heisenberg wrote his epochal paper to which he gave the title, "Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen," with the word "Umdeutung," or "reinterpretation," signaling his adherence to the Einsteinian strategy.⁷

Bohr, however, was adamantly opposed, taking the Kantian tack that position and momentum were inherently classical concepts, and while necessary for us humans were inherently inapplicable to events in the microworld except in certain loose and strictly inaccurate ways. Heisenberg, who was all of 25 in spring 1927, when he wrote a paper on his approach, was deeply swayed by his mentor Bohr, whom the quantum revolutionaries had nicknamed "the Pope." Though Heisenberg redrafted his paper outlining the approach several times in a futile effort to placate Bohr, neither Bohr nor Heisenberg wound up satisfied.⁸ This paper bore the title, "Über den anschaulichen Inhalt der quantentheoretischen Kinematic und Mechanik,"9 with the word "anschaulichen," or "intuitive," signaling this time its Kantian background and ambition, for it set out to explain to classically trained physicists how quantum mechanics might be intuited or imagined in classical terms. Eventually, motivated largely by a desire to link arms with Bohr in a unified front, Heisenberg came around to consent to Bohr's formulation of what was soon called the "Copenhagen Interpretation" of quantum mechanics, ceasing to try to develop a nonclassical meaning to replace the classical terms. Only later did Heisenberg move away from Bohr, using the dramatic and apparently radical conclusions of Bohr's philosophically naive perspective as an incentive and inspiration to develop a more sophisticated approach. "Heisenberg," writes Heelan, "played Kant to Bohr's Hume."¹⁰

While Heelan was working on his dissertation in Louvain, Heisenberg was at the Max Planck Institute in Munich. Heelan corresponded with Heisenberg, visited him, and was given access to his archives. When Heisenberg read the final text, his only objection – significantly – was to Heelan's assertions of his early disagreement with Bohr. Heelan was able to point to historical and archival material proving the point, to which Heisenberg gave no response. Ten years later, however, Heelan, taking advantage of the taped interviews that Thomas Kuhn had with Heisenberg and the other principals of the quantum revolution (presently stored in the Archives for the History of Quantum Physics maintained by the American Physical Society and the American Philosophical Society), wrote an article, "Heisenberg and Radical Theoretic Change," on Heisenberg's

view of "scientific revolutions."¹¹ This taped material, collected in the sixties, was not available to Heelan at the time he was writing his dissertation. Heelan sent Heisenberg a prepublication copy of the text of this article to which Heisenberg responded with a letter spelling out his previous objections more clearly. The journal editor included Heisenberg's comments and Heelan's reply on unnumbered pages at the end of the published article. The body of the exchange is illuminating for the light it sheds on Heisenberg's early thinking, and Heelan's interpretation of it. Heisenberg wrote:

I think I can agree with most of your statements, but I would like to make one exception concerning the difference of opinions between Bohr and myself. I think that you overemphasize these differences, and I might mention in this connection a few passages of your paper. You say that "I attributed descriptive force to the newly interpreted variables while Bohr chose to speak of wave and particle 'pictures' which were not in his view true models of atomic phenomena." But I am sure that Bohr would have agreed if one would say that he attributed descriptive force to the pictures he used; but he would perhaps have added that he did not know what the word 'true' means, when you speak about true models of the atomic phenomena. With respect to the "blurring the distinction between signifier and signified" I may remind you of my discussions with Bohr on the problem whether the cut between that part of the experiment which should be described in classical terms and the other quantum theoretical part had a well defined position or not. I argued that a cut could be moved around to some extent while Bohr preferred to think that the position is uniquely defined in every experiment. For instance the water droplets in a cloud chamber could either be considered as the "signifier" for the motion of the electron or as being "signified" by the black lines on the photographic plate. Bohr and I sometimes disagreed when we tried to approach to the same goal (namely the interpretation of quantum theory) from different directions. But finally I did not see any important difference between the principle of complementarity and the reinterpretation of classical variables after I had understood that the relations of uncertainty are just a special case of complementarity. Perhaps you should formulate more clearly what you mean by such terms as "true models of atomic phenomena."1

Heelan replied as follows:

No model of atomic phenomena is of itself either true or false, only statements purporting to use the model to state what is the case are capable of being true or false. Statements are true, if they make the correct semantical use of the model and if they state what is in fact the case. Two kinds of models occur in the interpretation of quantum mechanics: one which Heisenberg preferred, constituted by the (nonclassical) mathematical formalism of guantum mechanics, and the other, which Bohr preferred. constituted by the (classical) wave and particle 'pictures' of complementarity. If true statements can be made by the use of both models, then clearly different semantical usages are involved. Bohr could make true statements and Heisenberg also: they approached the same goal (a true interpretation of quantum theory) from different directions. But this does not imply that Bohr and Heisenberg are using their respective models in the same way. I would hold, for example, that Heisenberg used the mathematical model literally of atomic phenomena, while Bohr used the wave and particle 'pictures' metaphorically of the same phenomena. Heisenberg's usage, I believe, was the more scientific, because, unlike metaphorical usage, it implied nothing that was hidden and oblique. By a 'true model of atomic phenomena', then, I mean one that, when correctly used, is used in a literal, as opposed to a metaphorical manner. By that, I do not mean to imply that there is no truth in metaphor, or less truth, but that in science, truth aims at non-metaphorical expression. Thus, Bohr and Heisenberg could both be right, but not right in the same way, since they used different models and hence different semantical rules to reach the goal of true expression. The route Heisenberg took, however, was in my opinion both more illuminating from a philosophical point of view, and more scientific in what it foreshadowed about the future development of physics.

Heelan's dissertation was published as *Quantum Mechanics and Objectivity*¹³ and his article 'Heisenberg and Radical Theoretic Change' was published in 1975.¹⁴ As would become characteristic, Heelan's work does not attempt to criticize the shortcomings of predecessors and stake a claim to a fully novel view. Rather, he attempts mainly to recover, restore, and repair the work of some thinkers – Heisenberg and Husserl in this case – and then to use that to address other seemingly contrary positions – here, a strict Bohrian interpretation of complementarity and the von Neumann – Wheeler objectivist model. The book's approach is partly Heideggerian and partly Husserlian, though Heelan saw anticipations in Aristotle and Aquinas as these were brought up to date by Bernard Lonergan.¹⁵

What's Heideggerian is the insistence on the moment prior to object-constitution, the context or horizon or world or open space in which something appears. This is the "ontological condition of possibility established by a milieu, which governs the kinds of systems and processes capable of taking place within the milieu."¹⁶ The actual appearing or 'phenomenon'¹⁷ is a second moment. This Heelan analyses in a Husserlian way by studying the intentionality structure of object constitution and insisting on the duality therein of its noetic and noematic poles. "The noetic aspect is an open field of connected scientific questions addressed to empirical experience; the noematic aspect is the response obained by the scientific experiment from experience. The totality of actual and possible answers constitutes a horizon of actual and possible objects of hu man knowledge and this we call a World."18 The world then becomes the source of meaning of the word "real," which is defined as what can appear as an object in the world. The ever-changing and always historical laboratory environment with all its everto-be-updated instrumentation and technologies belongs to the noetic pole; it is what makes the objects of science real by bringing them into the world in the act of measurement. Measurement involves "an interaction with a measuring instrument capable of yielding macroscopic sensible data, and a theory capable of explaining what it is that is measured and why the sensible data are observable symbols of it."¹⁹ But isn't it then a symbol of the real – the data – that is being observed, not the "real" itself? "Our answer is that the observable symbol can reveal a real property if it denotes or indicates the real presence of a variable whose intimate nature, though not per se representable in sensibility, is known, however, in some other way and simultaneously." Heelan continues, "We take the observable symbol to be the criterion of reality for something whose nature is known only as part of a complex relational totality expressed symbolically in linguistic or mathematical terms." Heelan later specifies this object to be the invariance underlying all theoretically possible data presentations.²⁰ Although this process sounds complex, Heelan points out, it is something we perform "continu ously and with ease in daily life,"21 for instance, we speak of the city of Dublin as a worldly entity, but we cannot comprehend it except as what is intended in a series of connected but partial views. What's different in the case of quantum phenomena is that "deterministic and statistical elements are organically and inseparably united."22 Deterministic elements are involved in the wave function, which is an idealized formula from which the results for individual and concrete acts of measurement can be computed and statistically correlated. (These results are treated as Husserlian 'profiles' or, using the Dublin metaphor, 'individual views of the same worldly object'). "[T]he strict object of quantum mechanics is not an idealized formula of an individual system, but the individual and concrete instance of a physical system."²³ Thus the difference between quantum and classical physics does not lie in the intervention of the observer's subjectivity but in the nature of the quantum object: "[W]hile in classical physics this is an idealised normative (and hence abstract) object, in quantum physics the object is an individual instance of an idealised norm."24 For while in classical physics deviations of variables from their ideal norms are treated independently in a statistically based theory of errors, the variations – statistical distribution – of quantum measurements are systematically linked in one formalism. The apparent puzzle raised by the "reduction

of the wave packet" is thus explained via an account of measurement. In the "orthodox" (von Neumann and Wigner) interpretation, the wave function is taken to be the 'true' reality, rather than any empirically given 'symbol' of that reality. Consequently, the act of measurement is seen as changing the incoming wave packet into one of its com ponent eigen functions by an anonymous random choice. The sensible outcome of this change is the eigen value of the outgoing wave function which is read from the measuring instrument. The agent of this transformation for von Neumann and Wigner was the human spirit or mind as a manipulator of mathematical models.

Heelan also sees this "reduction" of the wave packet as depending on the conscious participation of the scientist-subject, but through a much different process. The wave formulae relate, not to the ideal object in an absolute sense, apart from all human history, culture, and language, but to the physical situation in which the real object is placed - an ensemble or system which admits of numerous potential experimental realizations. The reduction of the wave packet then "is nothing more than the expression of the scientist's choice of a measuring process which is different from the means used to prepare the pure state" prior to the measurement.²⁵ The wave function describes a situation which is imperfect as a fact of the real world. That does not mean there is more-to-be-discovered ("hidden variables") which will make it a part of the real world, nor that only human participation is able to bring it into the real world, but that what becomes a fact of the real world does so by being fleshed out by an instrumental environment to one or another complementary presentations. Heisenberg, Heelan claims, expressed this implicitly in his matrix mechanics: the theory only provides an account of possibilities, while the actuality is what appears in the experimental situation. Quantum mechanics, therefore, testifies in turn to what Heelan calls the "polymorphous" character of human knowledge:

If there is one conclusion which imposes itself before all others as a result of the inquiry we have made, it is the ambiguity hidden in the sense of the term "physical reality." This is founded in turn upon the underlying polymorphism of the human way of knowing reality. The neglect of some elements of this polymorphic consciousness, or undue emphasis on certain aspects of it, are the roots from which spring a multiplicity of epistemological difficulties; for in every question there is a hidden structure directing implicitly the search for answers... [P]rior even to the formulation of the answer [this hidden structure imposes an a priori] structure upon the answer even before it is formulated. This hidden structure is the domain of intentionality and, like the nine-tenths of an iceberg below water, it lies perilously below the level of our cognitive activities. Because of failure to appreciate this, especially wherever positivism or linguistic analysis is dominant, many ontological and epistemological discussions tend to founder; for, in such cases, problems are generally formulated uniquely in the light of the one-tenth that is in public view.²⁶

Heelan does not fail to notice that, by denying the existence of universal and necessary laws of scientific phenomena, quantum mechanics had a significant impact on the history of philosophy by undermining Kant's metaphysics. "This collapse of the most prestigious of classical metaphysical schemes was certainly one of the major contributing causes of the practical hegemony of positivism in scientific circles during the years following the discovery of relativity and quantum mechanics."²⁷

After publishing *Quantum Mechanics and Objectivity*, Heelan began to generalize the continentally based approach to the philosophy of science that he had worked out for quantum mechanics, and wrote several papers using continental philosophy to explore the interrelationship of intentionality, horizon, objectivity, and inquiry as a form of life in natural sciences.²⁸ In 1970, he wrote two papers fashioning these insights into a quantum logic.²⁹ Ordinary logic is propositional, and its truth or falsity concerns

statements of fact. The logic of quantum mechanics – the ordering of its empirical propositions – involve paradoxes which defy resolution within traditional logic. Several people, including G. Birkhoff and John von Neumann, therefore had proposed that quantum mechanics implies a non-classical "quantum logic," and proposed as well that this would be a universal logic to which ordinary logic would be an approximation in the same way that Galilean space/time geometry is an approximation to the Einsteinian space/time geometry of general relativity.³⁰ But Heelan concluded that the origin of these paradoxes lay in fields other than physics, in their necessary relatedness to a - choice among contexts or horizons; he invoked the continental insight that facts, when they appear, only do so in a relevant context or against a relevant horizon.

What is the effect of different contexts/horizons on what may purport to be the same fact? If the different contexts/horizons are mutually compatible, the fact need undergo no change with a switch from one context or horizon to another – as is generally the case, for instance, in classical physics. But if the different contexts/horizons interfere – if they are "entangled" with one another – then the fact will appear changed depending on whether it tries to appear in the simultaneous entanglement of both contexts/horizons. This is a function of the context- or horizon-dependence of every fact and such entanglements are not the exclusive province of quantum mechanics. "The point I am making is that one does not have to look to physics to find quantum logic. One finds it in the meta-[logic] of context-dependent statements."³¹ For instance, criticizing Putman and Finkelstein's formulation of quantum logic in subjunctive conditionals, which are then subject to various logical operations, Heelan says:

Consider the sentences: 'If I were drunk, I would dance a jig' and 'If I were sober, I would trim the hedge'. The former implies I am not drunk; the latter implies I am not sober. What then would the onjunction of the two sentences imply? If the basic sentences of quantum mechanics were subjunctive conditionals, the antecedents of the basic sentences would include all the mutually exclusive physical conditions into which the system could be placed. Just as in the example I have chosen and for the same reason, if a conjunction of a set of basic sentences were formed, it would not be clear what such a conjunction would imply.³²

The apparent paradoxes arise when one attempts to order such context-dependent statements while forgetting their context-dependence and overlooking the possibility that the contexts interfere or are entangled. One may inquire into something and choose a certain (e.g., scientific) context in which to pursue the inquiry – but one could have chosen other (e.g., visual) contexts, in which the products of the inquiry would have been different. Heelan then attempted to describe that relationship via his own context-dependent quantum logic, which he frequently represented graphically as a sextagonal figure or lattice (Fig. 1).

The lower (forking) point, L_0 , represents the possibility of discourse branching out into two (incompatible) but not simultaneously realized contexts/horizons (here, scientific and visual), while the upper (juncture) point, L_{AB} , the possibility discourse when the two branches are simultaneously realized and actually 'entangled.' And the two "arms" of the figure, $L_A \rightarrow L'_B$, and $L_B \rightarrow L'_A$, represent two isolated but practically incompatible contexts. The point is that human inquiry is constantly faced with the challenge of such competing and antagonistic branchings that are reconciled in practice in one of three ways: they ultimately rejoin, die out, or branch still further.

This lattice figure, and an account of the contextual logic associated with it, would appear again and again in Heelan's work in the following years, including *Space-Perception and the Philosophy of Science*.³³ The earlier accounts of contextual logic

postulated the lattice as mirroring the structure that thinking followed, while the later, more fully developed and more Heideggerian accounts present the lattice process as emerging out of the structure of thinking itself.³⁴ These later accounts appropriate the Heideggerian insight that words and ideas don't *mirror* a structure of reality across a gap, as it were, that is antecedent to them, but rather that thinking brings them together using words and ideas. The reciprocity between words and things transpires in a horizon or praxical space in which words and things, subject and object arise together.



Figure 1: The complemented Lattice of L_A (Scientific) and L_B (Visual). L_O is the greatest lower bound that identifies the common possibilities of predication that do not include L_A or L_B . L_{AB} is the least upper bound that is the most general descriptive language that includes the possibilities of L_A and L_B .

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Some of these later articles explore the application of contextual logic to the "mysteries" of quantum puzzles, such as Schrodinger's Cat Paradox³⁷ and Bell's Theorem (a series of unpublished papers). Other articles explored contextual logic at work in areas other than science, such as book cataloguing,³⁸ the logic of the social sciences (where con text is critical in describing things),³⁹ and – most notably – visual perception.⁴⁰ Heelan would use use optical illusions – including the Hering, Müller-Lyer, and Moon illusions, and the famous duck-rabbit image – to show that their contradictions and seemingly puzzling features arise from the way the images are

connected with a variable imagined visual background – in contrast with ordinary "non-puzzling" perception where the imagined background is fixed.⁴¹

Consider, again, the lattice in Figure 1. The lower point, Lo, comprises representational elements of a 'pictorial language' which could speak of ducks or rabbits, but is no more than marks on paper. L_A comprises only the pictorial elements of a duck and L_B comprises only the pictorial elements of a rabbit. The upper point, L_{AB} , contains the complete set of pictorial elements of both ducks and rabbits, but there happens to be an overlap among the pictorial elements that can be used to portray either a duck or a rabbit. L'_{B} , the language directly above L_{A} but before L_{AB} , is an 'extended duck language' comprising all the pictorial elements that could be used to portray ducks, but which includes some that could also be used to portray rabbits, while L'_{A} is an "extended rabbit language" which comprises all the pictorial elements that could be used to portray rabbits, but which also includes some that could be used to portray ducks. However, the peculiar thing about the duck-rabbit illusion is the relative poverty of L'_{B} and L'_{A} in relation to L_{A} and L_{B} , for one generally sees the figure either as duck or as a rabbit, and not as something in between. This is principally a function of the absence in the imagined visual back grounds of plausible intermediary types between ducks and rabbits. In most of the contradictions we encounter in visual space – whether they be in the pictorial space of Van Gogh's painted rooms or the architectural space of Arnheim's churches, to use two of Heelan's favorite examples - the conventional choice and use of one language, say, scientific, makes something appear while also opening it to various task-oriented questioning, say, within everyday experience. This inevitably reveals more than is spoken of in the conventional language.

More recently Heelan has addressed contextual logic not in terms of horizons but in the more comprehensive terms of what he calls task orientation.⁴² Task orientation assumes that a fact or object is in a horizon precisely because it responds to a familiar task-oriented interest that is constitutive of that context or horizon. This is a function of a worldly goal or orientation and raises the possibility of addressing the back-andforth relation between objects and horizon.

Heelan's approach to the philosophy of science points to new and productive ways for it to explore hitherto barren territories: to mention one in which I have written, the nature of the experimental process, or the staging of an action in order to understand the still enigmatic present.⁴³ In this process, scientific objects are often not known at first with Cartesian clarity. They often have to be brought into focus, somewhat like the ship Merleau-Ponty describes that's run aground on the shore, whose spars and masts are at first latent and mixed confusingly with the forest bordering on the sand dune, producing a vague tension and unease, until suddenly our sight is recast and we see a ship, accompanied by a feeling of satisfaction as the tension is relieved. In the laboratory, however, there is an important difference, for what is at first latent and then recognized is brought forward in an actively structured and programmed process. We are staging what we are trying to recognize – we built both the ship and the environ-ment in which we try to separate it out from its sourroundings. As a result, the very way we are staging it may interfere with our ability to recognize it, and we may have to alter how we are staging the experiment before what we are seeking comes into relief.

The value of Heelan's work on quantum mechanics thus goes far beyond teaching us how to read Heisenberg's thoughtful and earnest but often awkward writings on the

nature of quantum mechanics. Heelan's work revitalizes the foundations of the philosophy of science in ways that are able to overcome impasses confronted by analytic-inspired approaches. It does so by exploiting the key insight of continental philosophy that the most fundamental connection between human beings and world is not an epistemological one, or one based first and foremost on knowledge, but rather an ontological one, or one based on the (always historical and local) human life activity of which knowing the world is constitutive. Heelan's work incorporates the classic triad of orienting ideas of hermeneutical philosophy of science: the priority of meaning over technique, the priority of the practical over the theoretical, and the priority of situation over abstract formalization.⁴⁴ Analytic approaches often deride such issues as metaphysical, and assign metaphysics in turn to a place "somewhere between mysticism and crossword puzzles."45 But these approaches wind up sneaking an (unexamined) metaphysics back in through the side door, in the form of all the baggage accompanying the assumption that the primary relation of human beings to the world is cognitive. But the world grasped by scientists according to Heelan – like the world grasped by perceivers according to Merleau-Ponty – is always richer than the concepts, techniques, and theories which they use to grasp it. Every LA challenged by an LB will have to develop an L'_B. And every L'_B will seek incorporation with an L'_A into an L_{AB}. The philosophy of science Heelan offers us leaves science undivorced from life: experimental life.

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NOTES

¹ M. Frayn, *Copenhagen* (London: Methuen, 1998), 73.

² N. Bohr, *Atomic Theory and the Description of Nature* (Cambridge: Cambridge University Press, 1934), 54.

³ F. Wilczek, "What Did Bohr Do?" *Science* 255 (1992): 346. Cf. M. Beller, "The Rhetoric of Antirealism and the Copenhagen Spirit." *Philosophy of Science* 63 (1996): 183-20.

⁴ P. A. Heelan, *Quantum Mechanics and Objectivity* (Nijmegen: Nijhoff, 1965), 95-7, 133.

- ⁵ R. Crease, *The Play of Nature* (Bloomington: Indiana University Press, 1993), 140-1.
- ⁶ Heelan, *Quantum Mechanics and Objectivity*, ix.
- ⁷ W. Heisenberg, "Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen," Zeitschrift für Physik, 33 (1925): 879-893.

⁸ See M. Beller, "The Rhetoric of Antirealism and the Copenhagen Spirit." *Philosophy of Science* 63 (1996): 183-204 for a technical review, and R. Crease and C. Mann, *The Second Creation: Makers of the Revolution in 20th Century Physics* (New York: Macmillan, 1986. Repr. Rutgers Univ. Pr. 1996). Ch. 4 for a nontechnical review. ⁹ Heisenberg, "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." *Zeitschrift für Physik*, 43 (1927): 172-198.

¹⁰ Heelan, *Quantum Mechanics and Objectivity*, 48.

¹¹ Heelan, "Heisenberg and Radical Theoretical Change," *Zeitschrift für allgemeine Wissenchaftstheorie*, 6 (1975): 113-136, and following: 136.

¹² Heelan, "Heisenberg and Radical Theoretical Change," following 136.

¹³ Quantum Mechanics and Objectivity (Nijmegen: Nijhoff, 1965).

¹⁴ *Ibid*.

¹⁵ B.J.F. Lonergan, *Method in Theology* (London: Darton, Longman and Todd, 1972).

¹⁶ Heelan, Quantum Mechanics and Objectivity, 166.

¹⁷ *Ibid.*, 16.

¹⁸ *Ibid.*, x; also 3-4.

¹⁹ *Ibid.*, 30-1.

²⁰ Heelan, *Space-Perception and the Philosophy of Science* (Berkeley: University of California Press, 1983); "The Scope of Hermeneutics in Natural Science," *Studies in the History and Philosophy of Science* 29/2 (1998), 273-98; and [with Jay Schulkin], "Hermeneutical Philosophy and Pragmatism: A Philosophy of Science," *Synthese* 115 (1998), 269-302.

²¹ Heelan, Quantum Mechanics and Objectivity.

²² *Ibid.*, 107.

²³ *Ibid.*, 109.

²⁴ *Ibid.*, xii.

²⁵ *Ibid.*, 184.

²⁶ *Ibid.*, 156.

²⁷ *Ibid.*, 141.

²⁸ For example, Heelan, "Horizon, Objectivity and Reality in the Physical Sciences." *International Philosophical Quarterly* 7 (1967): 375-412.

²⁹ Heelan, "Quantum Logic and Classical Logic: Their Respective Roles," *Boston Studies in the Philosophy of Science XII*, 318-349; "Complementarity, Context-Dependence and Quantum Logic." *Foundations of Physics* 1 (1970): 95-110.

³⁰ Heelan, "Quantum Logic and Classical Logic," 322; or, one might add, to the Riemannian geometry of vision; Heelan, *Space-Perception and the Philosophy of Science* (Berkeley: University of California Press, 1983).

³¹ Heelan, "Quantum Logic and Classical Logic," 335.

³² *Ibid.*, 341.

³³ Heelan, *Space-Perception and the Philosophy of Science* (Berkeley: University of California Press, 1983), 178-187.

³⁴ "Why a Hermeneutical Philosophy of the Natural Sciences?" in R. Crease, ed., *Hermeneutics and the Natural Sciences* (Dordrecht: Kluwer, 1997), 13-40.

³⁵ Heelan, *Space-Perception and the Philosophy of Science* (Berkeley: University of California Press, 1983), 178-187.

³⁶ "Why a Hermeneutical Philosophy of the Natural Sciences?" in R. Crease, ed., *Hermeneutics and the Natural Sciences* (Dordrecht: Kluwer, 1997), 13-40.

³⁷ *Ibid*.

³⁸ Heelan, "The Logic of Changing Classificatory Frameworks" in J. Wojciechowski, ed., *Proceedings of the International Conference on the Classification of Knowledge* (Munich: Verlag Documentation, 1974) 260-274.

³⁹ Heelan, "An Anti-epistemological or Ontological Interpretation of the Quantum Theory and Theories Like it," in B. Babich, et al., eds., *Continental and Postmodern Perspectives in the Philosophy of Science*, (Aldershot/Brookfield, VT: Avebury Press, 1995), 55-68.

⁴⁰ "Toward a New Analysis of the Pictorial Space of Vincent van Gogh." Art Bull. 54 (1972): 478-492.

 ⁴¹ Heelan, Space-Perception and the Philosophy of Science, Ch. 5.
⁴² Heelan and Schulkin, "Hermeneutical Philosophy and Pragmatism: A Philosophy of Science."

⁴³ Crease, *The Play of Nature*.

⁴⁴ Crease, Hermeneutics and the Natural Sciences, 262-3.
⁴⁵ Heelan, Quantum Mechanics and Objectivity, x.