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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

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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, momentum, energy, and so on; when that packet is measured – by a macroscopic (non-quantum) 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."[12]

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 (non-classical) mathematical formalism of quantum 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 human 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 ever-to-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 "continuously 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

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