PATRICK AIDAN HEELAN

THE OBSERVABLE

Heisenberg's Philosophy of Quantum Mechanics

FOREWORD BY MICHEL BITBOL

EDITED WITH A FOREWORD BY BABETTE BABICH

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HISTORY AND PHILOSOPHY OF SCIENCE

Heresy, Crossroads, and Intersections

Paolo Palmieri
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Foreword

MICHEL BITBOL

This is not an ordinary book on the philosophy of quantum physics. Patrick Heelan started working with Werner Heisenberg in the early 1960's while he was associated with the Edmund Husserl Archives at the University of Leuven in Belgium, and his research about the meaning of quantum mechanics bears a strong mark of this immersion in the heartland of phenomenology, hermeneutics and transcendental epistemology. Being a member of the Edmund Husserl Archives at the Ecole Normale Supérieure, in Paris, France, I can appreciate with a flavor of complicity the depth and extent of this philosophical influence.

About the latter, it must be said that, irrespective of one's position in the long-term debate between analytic and "continental" philosophies, and independently of any judgment about which one of these two philosophical strategies is best suited for clarifying the meaning of modern physical theories, the "continental" approach has the advantage of being akin to the one pursued by the creators of quantum mechanics themselves. Even when they disagreed, the physicists who first elaborated the formalism and tentative interpretations of this theory were debating with common philosophical references, and with the shared cultural background of a post-Kantian and neo-Kantian German tradition. Thus, although he criticized the original Kantian orthodoxy, Einstein was quite impressed by the neo-Kantian reading of relativity theories offered by Ernst Cassirer;[1] Bohr was exposed to Kierkegaard's existential philosophy and to post-Kantian ideas through Harald Höffding's lectures;[2] and Schrödinger did not hide the breath-taking similarities between his philosophical ideas and Schopenhauer's.[3] As for Heisenberg, who is the central figure and theme of Patrick Heelan's book, he grew in the atmosphere of a heated debate about Ernst Mach's positivism,[4] he then received a strong Kantian input from his student Karl-Friedrich von Weizsäcker and from the philosopher Grete Hermann,[5] and he finally had a long-standing intellectual relationship with the hermeneutical phenomenologist Martin Heidegger.

The indisputable symptom of a transcendental and phenomenological influence on both Heisenberg and Heelan can be seen in the unconventional orientation of their philosophy of physics. Far from restricting their discussion to a metaphysical speculation about what the world is like according to quantum mechanics, or about how the symbols of this theory hook on to things out there, they systematically impose a *reflective* direction to their philosophical inquiry. They devote most of their effort to assessing the "indivisibility" of experimental phenomena, underpinned by the *inextricable* connections between the quantum mechanical observer (with various instrumental extensions) and its purported object. These connections in turn imply an analysis of the instruments, mathematical symbolism and type of language which are essential to the practice of microphysics. In particular, it is shown that the observer-object entanglement expresses itself through the context-dependence of any description of micro-attributes, and through the correlative use of contextual, rather than universal, languages. As for the statement of contextuality itself, it can

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[1] Letter of Einstein to Cassirer, June 5, 1920: "I think that your treatise is very well suited to clarify philosophers' ideas and knowledge about the physical problem of relativity." *The Collected Papers of Albert Einstein, Volume 10, The Berlin Years: Correspondence, May–December 1920, and Supplementary Correspondence, 1909–1920* (Princeton: Princeton University Press, 2004), 182.

[2] Jan Faye, *Niels Bohr: His Heritage and Legacy* (Dordrecht: Kluwer, 1991).

[3] Cf. Erwin Schrödinger, *My View of the World* (Cambridge: Cambridge University Press, 1951); Michel Bitbol, *Schrödinger's Philosophy of Quantum Mechanics,* (Dordrecht: Kluwer, 1996).

[4] Werner Heisenberg, *Physics and Beyond* (New York: Harper & Row, 1971), Chapter III.

[5] Grete Hermann, *Les fondemements philosophiques de la mécanique quantique* (Paris: Vrin, 1996), French translation of Hermann, *Die naturphilosophischen Grundlagen der Quantenmechanik,* Abhandlungen der Fries'schen Schule, N. F. Band 6, Heft 2: 69–152 (Heidelberg: Springer, Sonderdruck bei Hirtzel, 1935).

only be made by way of a meta-contextual language[6] which is consciously adopted throughout the book.

Heelan's analysis of the observer-object complex accordingly develops into the idea of a *hermeneutic circle,* which is a mutual relation between (i) a set of contextual preconceptions (about a text or a domain of scientific investigation), and (ii) the way preconceptions modulate the statement of those facts which could be used to test them. Here, the concept of a hermeneutic circle is generalized in a Heideggerian spirit so that the fabric of our measuring apparatuses, their scale, the way we interpret their indications, and even the whole "life world of human scientific culture,"[7] partake of the contextual preconceptions of inquiry. From that point on, it becomes clear that focusing attention exclusively onto the hypothetical object of physics or onto the terms that are employed to denote it would be naive, since the concept of this object emerges from the hermeneutic circle of our investigation process. The belief that remaining forgetful of the course of and the instruments of research is harmless for our understanding of physics can be ascribed to a remarkable historical circumstance that enabled the rise of classical science, but is now obsolete. Indeed, at this early stage of the science of nature, the knowing subject could be shrunk into an almost invisible origin of spatial coordinates, and ignored straightaway.[8] As a consequence, the relation between subject and object was reduced to a sort of "epistemological parallelism,"[9] in which a ghost-like subject faithfully expressed (but did not engage in) the physical processes. And the hermeneutical process of research could be oversimplified into a transparent reading of what Galileo called the "grand book (of) the universe."[10]

At this point, however, another pitfall must be avoided. Let's accept that, in the quantum domain, the subject must be construed as "embodied," thus establishing a kind of material continuity between it and the micro-object of study. This does not entail that the subject, together with its instrumental extensions,

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[6] Patrick Aidan Heelan, TO Chapter I (the capital letters TO abbreviate the title of the current book: *The Observable);* Heelan, "Quantum Logic and Classical Logic: Their Respective Roles," *Synthese,* **22** (1970): 3–33. Also, Michel Bitbol, *Mécanique quantique: une introduction philosophique* (Paris: Flammarion, 1996); Bitbol, "Quantum mechanics as generalized theory of probability," *Collapse,* **8** (2014): 87–121.

[7] Heelan, TO, Introduction, xxxiv.

[8] Hermann Weyl, "The coordinate system is, as it were, the residue of the annihilation of the ego." *Philosophy of Mathematics and Natural Science* (Princeton: Princeton University Press, 2009), 123.

[9] Heelan, TO Chapter X, 107.

[10] Galileo Galilei, *The Assayer*, in: Stillman Drake, *Discoveries and Opinions of Galileo* (New York: Doubleday and Co., 1957), 237.

should be treated exclusively like an *object* of physics (especially of quantum physics); for this confusion of two epistemological categories would only give rise to a series of intractable paradoxes, whose best example is the celebrated measurement problem of quantum mechanics.[11] Instead, the subject's embodiment motivates the introduction of a new kind of subject-object cut, which separates neither the non-physical from the physical, nor one spatial domain of objects from another spatial domain, but rather the "*meaning-making process*"[12] from what is *meant* by it. Here, far from forcing one to ascribe the subject the status of some meant object, its embodiment is construed as a contribution to the meaning-making procedure. Along with Husserl's distinction between *Leib* [*lived* body] and *Körper* [*objectified body*], the instrumentally enhanced body of the quantum mechanical observer is taken as a structured precondition of knowledge rather than a known object (be it an object of physics or psychology). In other terms, the embodied subject is ascribed a *transcendental* position: the position of a background framework of any act of cognition, rather than a cognized element.[13]

A correlative feature of Heelan's approach of Heisenberg's view of physics that fits well with the conceptual equipment of transcendental epistemologies is its persistent, yet low profile, use of the duality of form and content. This couple of concepts here occasionally translates into a contrast between the Husserlian *noema* (structure of an intentional act directed towards some object) and *noesis* (mental process associated to this act).[14] More specifically, it also translates into a duality of theoretical structured expectations and observable features. However, Heisenberg's views partly differed from Kant's conviction that the structure of knowledge could only be ascribed to the cognitive faculties of the knowing subject, and from Kant's agnosticism concerning the alleged structure of the "noumenal" world.

To begin with, *observability* of a certain kind was taken by Heisenberg as an appropriate criterion of *reality*. So far, his position remained in good agreement with Kant's claim that the passive reception of sense-impressions is a mark of the finiteness of the knowing subject, and thereby the sign of it's encounter with something that exceeds it. But can one go further and say that those theoretical

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[11] Peter Mittelstaedt, *The Interpretation of Quantum Mechanics and the Measurement Process* (Cambridge: Cambridge University Press, 1998). Mittelstaedt here points out that, in order to avoid the measurement problem from the outset, one must give a meta-theoretical status to (at least part of) the measuring instruments and process. If this is not done, if the subject-side of the measuring process is treated like an object of the theory to be tested (here quantum mechanics), paradoxes of self-reference arise.

[12] Heelan, TO Chapter XV, 170.

[13] Maurice Merleau-Ponty, *Phenomenology of Perception* (London: Routledge, 2005).

[14] Heelan, TO Chapter XV.

structures that can be filled (or confirmed) by observation are, solely on the basis of this fact, faithful images of "reality out there"? It looks like Heisenberg came within a hair's breadth of holding this (quite un-Kantian) scientific realist thesis. And Heelan repeatedly insists on Heisenberg's quest for a "real order (…) totally independent of any knowing subject,"[15] by way of theoretical physics; a quest that could only be supported by Heisenberg's strong inclination towards a Platonic or Pythagorean view of mathematical structures.[16] Heisenberg indeed looked for aspects of these structures which are interpretable as truthful representations of some independent realm of being, *despite* the strong entanglement he was first to recognize between reality and the material or semantic instruments of knowledge.[17] He furthermore did not hesitate to treat experimental phenomena as mere signs of something else, namely of the entities which are probed by the measuring apparatuses and adumbrated by theoretical structures. He thus clearly departed, in the domain of physics, from the dominant feeling of transcendental phenomenology according to which "being is *identical* to the phenomenon."[18] At the end of his career, Heisenberg even felt that he had finally identified an ontology which is appropriate to the quantum formalism: not, of course, the standard ontology of *actual* entities permanently located in space-time (the so-called "particles"), but the pre-spatial Aristotelian ontology of *potentia* (or power), partly described by what he calls the "probability function"[19] of quantum mechanics.

However, the way Heisenberg elaborated his ontological view of the world gives me serious doubts as to whether he had truly relinquished a transcendentalist philosophy of science in favor of a more standard realist position. In his case, it seems to me, a renewed, neo-Kantian, version of transcendental epistemology is elaborated under the guise of scientific realism. After all, what is the defining feature of neo-Kantianism with respect to original Kantianism? It is its adoption of a relativized and historicized version of the synthetic *a priori* forms of cognition,[20] which were considered as unique and immutable by Kant. When one compares Bohr's and Heisenberg's conceptions of quantum mechanics, they can easily be understood in terms of this difference between semi-orthodox Kantianism and neo-Kantianism.

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[15] Heelan, TO Chapter I, 10.

[16] Werner Heisenberg, *Physics and Philosophy* (Hassocks: Penguin, 1990), 55.

[17] Heisenberg, *Philosophie: le manuscrit de 1942* (Paris: Seuil, 1998), French translation of: Heisenberg, *Ordnung der Wirklichkeit* (Munich: R. Piper GmbH & KG, 1989).

[18] Eugen Fink, *Proximité et distance* (Paris: Jérôme Millon, 1994), 120.

[19] Heisenberg, *Physics and Philosophy, op. cit.*, 40.

[20] Michael Friedman, *Dynamics of Reason* (Chicago: Center for the Study of Language, University of Chicago Press, 2001).

As Heelan cogently points out, "the Kantian element in Bohr's philosophy led him to take the position that it was not in our power to construct non-classical descriptive concepts to cover the quantum domain."[21] A chain of consequences follows, according to Bohr. Firstly, classical concepts appropriate to our direct environment can by no means be overcome or dispensed with; they represent the unshakable conditions of possibility of any communicable knowledge. Secondly, *observability* is defined within the framework of such concepts, since it consists of an ability to manifest somewhere in the classical space-time pattern. Thirdly, *objectifiability*, in the sense of a power to disentangle statements about natural objects from their epistemic context of validity, is made possible only by classical concepts. Yet, since these concepts are adapted to nothing else than the mesoscopic domain which approximates the size of our human body, the quantum domain in principle escapes their range of validity. The only thing that can be done in quantum physics is to use classical concepts in order to describe the effects of the interaction of the micro-world with measuring devices, and then complement these concepts with a non-classical mathematical symbolism whose sole purpose is to afford (probabilistic) predictions of measurement outcomes. Here, quantum theory tends to be taken as a mere "paradigm", namely "a set or rules for the use of language or a set of models for an activity of a certain kind,"[22] with little or no aspiration to open a window into the ontology of quantum mechanical systems.

In the late part of his career, Heisenberg distanced himself with most of these strong axioms of Bohr's interpretation of quantum mechanics. According to him, new concepts could be elaborated beyond the circle of the classical world, provided one relies on the generative power of the theoretical formalism. Any such concept is specified "by *implicit definition* through the interpretation of those mathematical relations which the theory established between its own primitive terms."[23] On this basis, "observability" of a feature is established independently of the classical system of concepts. For, to claim that a feature pertaining to the new domain has been observed, it is sufficient to display an event that can be understood in terms of the current theoretical (and conceptual) system. Observability in this sense being the touchstone of our grip on reality according to Heisenberg, he could hope to build on it and elaborate a set of *ontological* propositions by drawing from "the theoretical (explanatory) linguistic framework of [the] physical theory."[24]

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[21] Heelan, TO Chapter VIII, 81.

[22] Heelan, TO Introduction, 3.

[23] See below: Heelan, TO, Chapter VII, 65.

[24] See below: Heelan, TO, Chapter II, 26.

Now, looking closely at the *method* he used in order to elaborate this unconventional ontology, we find that Heisenberg relied on mathematics in order to perform two tasks which are typically neo-Kantian: (i) redefining objectivity and (ii) delineating a new field of objective phenomena according to the redefined acceptation of the concept of objectivity.

Indeed, mathematics enables physicists to achieve "computational synthesis of phenomena"[25], an operation which clearly carries on with the global Kantian project of constituting domains of objective knowledge. For, according to Kant, synthesis represents "the act of putting different representations with one another, and of comprising their manifoldness in one cognition"[26]; and it is the resulting unity of phenomena in one cognition that plays the role of an object. Yet, this way of performing the synthesis by mathematics is much more general than the one, advocated by Kant, which uses standard forms of cognition adapted to our mesoscopic environment. Such generalization rather agrees with the relativized and historicized construal of the synthetic *a priori* which was developed by neo-Kantian philosophers against their Kantian legacy. Besides, it must be pointed out that mathematics exerts its synthetic power by using tools such as *groups* of transformations, which automatically implement a broadened conception of objectivity *qua* equivalence of various standpoints towards a common target. Mathematics thus contributes to a redefinition of the concept of objectivity, in the direction that Heisenberg found suitable to overcome the restrictive notion of objects which applies in classical science.

In point of fact, according to Heisenberg, quantum physics is a domain in which objectivity in the maximal sense of "objectifiability," namely complete detachment with respect to the experimental and life-world context, cannot be reached. Instead, in this case, objectivity can only be obtained in the minimal sense of "publicity," or universal inter-subjective validity.[27] Invariance with respect to a set of standpoints, positions, or instruments (as formalized by mathematics) does not mean outright independence from them. But the dream of an ontology is *ipso facto* a dream of figuring out something entirely independent from the cognitive process. If such independence cannot be arrived at, as Heisenberg himself declared, ontological claims look like delusions. The best candidate Heisenberg had for his ontological project, namely the formalized *potentiality* to manifest, is so

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[25] See Bitbol, Jean Petitot, Pierre Kerszberg (Eds.) *Constituting Objectivity: Transcendental Perspectives on Modern Physics* (Frankfurt am Main: Springer Verlag, 2009), 3.

[26] Immanuel Kant, *Critique of Pure Reason*, B103, (Indianapolis: Hackett Publishing, 1996), 130.

[27] Heelan, TO, Chapters I, XI.

obviously dependent upon the variegated conditions of its actualization that it can hardly be taken as more than a ghost-like reification of a unified tool applied for prediction of actual experimental outcomes. This predictive tool is publicly valid, hence objective in the minimal sense; but it is not totally independent from the contexts in which what it predicts can manifest, and it is therefore neither objectifiable nor ontologically interpretable.

Did Heisenberg overlook, in the later part of his life, that "it is *within this intentional space* [*of human consciousness*] that the 'cut' between subject and object is made"?[28] Did he dream to reverse once again the historical trend he had identified, according to which "post-moderns look away from the natural history of the cosmos and look inwards, back to the human observer's role in constituting the complexity of worlds"?[29] If Heisenberg had clung to the most challenging aspects of the epistemological revolution he had triggered, he would have agreed with Ernst Cassirer that "true objectivity never lies in empirical determinations, but only in the manner and way, in the *function,* of determination itself."[30] He would have interpreted the mathematical symbols of quantum mechanics as a momentous step in the self-revelation of the *function* of constitution of objectivity, not as an insight into the ontology of the cosmos. Thanks to the rigor and clarity of Patrick Heelan's book, we now have the appropriate tool to take this step for ourselves.

Paris, February 2015

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[28] Heelan, TO, Chapter XV, 166.

[29] Heelan, TO, Chapter XI, 121.

[30] Ernst Cassirer, "Einstein's Theory of Relativity" in: Cassirer, *Substance and Function, and Einstein's Theory of Relativity* (Chicago: Open Court, 1953), 351.

Foreword

BABETTE BABICH

The Observable was finished in 1970, half a decade after the 1965 publication of Patrick Aidan Heelan's study of Werner Heisenberg's *phenomenological* and (as Heelan would later would reflect as inseparably) *hermeneutic* philosophy of science, originally articulated by way not only of Heisenberg's theoretical and mathematical thinking of physical science but an interpretative reading of Edmund Husserl's[1]

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[1] Noteworthy readings of Husserl's philosophy of science, in addition to the exemplary discussion Heelan offers in his own *Space-Perception and the Philosophy of Science* (Berkeley: University of California Press, 1983), include Thomas Ryckman, *The Reign of Relativity: Philosophy in Physics 1915–1925* (Oxford: Oxford University Press, 2004) as well as the contributions to Richard Feist (Ed.) *Husserl and the Sciences: Selected Perspectives* (Ottawa: University of Ottawa Press, 2004), including Pierre Kerszberg's contribution here, "From the Lifeworld to the Exact Sciences and Back" and see too the contributions to Carlo Ierna, Hanne Jacobs, and Filip Mattens (Eds.) *Philosophy, Phenomenology, Sciences: Essays in Commemoration of Edmund Husserl* (Frankfurt am Main: Springer, 2010). See too David Hyder and Hans-Jörg Rheinberger (Eds.) *Science and the Life-World: Essays on Husserl's Crisis of European Sciences* (Stanford: Stanford University Press, 2009). See too M. Esfeld, *Holism in Philosophy of Mind and Philosophy of Physics* (Frankfurt am Main: Springer, 2001) More broad discussion also bearing on science include R. Philip Buckley, *Husserl, Heidegger and the Crisis of Philosophical Responsibility* (Frankfurt am Main: Springer, 2010), Anastasios Brenner and Jean Gayon (Eds.) *French Studies in the Philosophy of Science: Contemporary Research in France* (Frankfurt

and Martin Heidegger's philosophies of science, and in Heidegger's case also of technologies/instruments. Heelan's *Quantum Mechanics and Objectivity*[2] was unusually path-breaking as Heisenberg was, as Heelan reports, both the subject of the study as well as a philosophical partner in reflective, scientific dialogue. *The Observable* develops that dialogue, expanded to reflections on Einstein, Bohr, and Schrödinger (with whom Heelan closely worked as an assistant during his years in Dublin) as well as Eugene Wigner (who influenced Heelan during his post-doc years at the Institute of Advanced Studies at Princeton University).

Heelan went on to apply and further develop these theoretical insights in his 1983 study, *Space-Perception and the Philosophy of Science*.[3] As Heelan's assistant during the writing of *Space-Perception and the Philosophy of Science*, the current editor learned to bring active hermeneutic and phenomenological principles to bear on the otherwise and still today limitedly analytic profile of professionally received philosophy of science. By the late 1970s and early 1980s a division in philosophy was already beginning to affect the reception of readings in the philosophy of science, to wit a division between 'analytic' and 'continental' philosophies of science. Heelan's work was key in the latter tradition along with, among others, Joseph Kockelmanns but also Ted Kisiel and Gerard Radnitzky and later names such as Hans-Jörg Rheinberger. In addition, there were other philosophers of science who also crossed the divide when it came to themes like the 'observable,' including Norwood Russell Hanson as well as others simply by dint of their iconoclastic character or personality, including most notably Paul Feyerabend (and Hanson in particular is also engaged in the text below). Several decades after this foment, two related book collections would appear, one at the turn of the century: a celebratory book on Heelan's work in the philosophy of science also reflecting texts inspired by his contributions to the study of art (including both the psychology

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am Main: Springer, 2009) and, from an earlier perspective, see Aron Gurwitsch and Lester E. Embree (Eds.) *Phenomenology and Theory of Science* (Evanston: Northwestern University Press, 1979) as well as Elisabeth Ströker, *The Husserlian Foundations of Science* (Washington, DC: Center for Advanced Research in Phenomenology, 1987). See too Debabrata Sinha, "Phenomenology as Philosophy of Science" in: Sinha, *Studies in Phenomenology* (The Hague: Martinus Nijhoff, 1969), 89–105 and cf. in the same volume, "Subjectivism in Phenomenology," 50–67.

[2] Patrick Aidan Heelan, *Quantum Mechanics and Objectivity: A Study of the Physical Philosophy of Werner Heisenberg* (The Hague: Nijhoff, 1965). See too Michel Bitbol's *Schrödinger's Philosophy of Quantum Mechanics* (Dordrecht: Kluwer, 1996) as well as Bernard d'Espagnat, *Conceptual Foundations of Quantum Mechanics* (Reading: Perseus, 1999) and *On Physics and Philosophy* (Princeton: Princeton University Press, 2013).

[3] Heelan, *Quantum Mechanics and Objectivity*.

and the phenomenology of perception and some of the issues in the present book already point in this direction) as well as theology[4] and very recently now in 2014, a reflective book collection, in memory of Heelan's friend and collaborator, Joseph Kockelmans, and co-edited with the Bulgarian philosopher of science, Dimitri Ginev who came to know both Heelan and Kockelmans during Ginev's time at the University of Pittsburgh.[5]

But as Michel Bitbol, a leading scholar in the philosophy of quantum mechanics and expert on Schrödinger, points out in his foreword above, the distinction between "analytic" and "continental" when it comes to quantum mechanics cannot but foreground a difference that not only makes no difference but more significantly invites the scholar to overlook key conceptual aspects in quantum mechanics.[6] Beyond its scientific and hermeneutic dimensionality, continental philosophy of science is not limited to a specific geographic location,[7] but includes the history of science as part of the philosophy of science as well as a sensitivity to context, and, especially when it comes to Heelan's work in the philosophy of science, an overtly *phenomenological* methodology.

This quick overview of the course of Heelan's intellectual trajectory from his 1965 book on *Quantum Mechanics and Objectivity* to his 1983 study of *Space-Perception and the Philosophy of Science* can permit one to draw the conclusion that the main problems of such a lifetime coincide with hard conceptual difficulties at the heart of physics, especially with respect to quantum theory and with respect to a theorist who does not shy away from questions of ontology, as Heelan points to Heisenberg's attunement to the explicitly Heideggerian language of ontology below. But there are what we may call real-life consequences that follow from the so-called analytic-continental divide. More is involved than a style of thinking and the profession of philosophy, like most academic disciplines, does not tolerate a thousand flowers blooming: some voices are included and some are not. This disciplining of the discipline is effected by political means: one is excluded from

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[4] Babette Babich (Ed.), *Hermeneutic Philosophy of Science, Van Gogh's Eyes, and God: Essays in Honor of Patrick A. Heelan* [Boston Studies in the Philosophy of Science, 225] (Dordrecht: Kluwer, 2002).

[5] Babette Babich and Dimitri Ginev (Eds.), *The Multidimensionality of Hermeneutic Phenomenology* (Frankfurt am Main: Springer, 2014). A third collection is due to appear dedicated to *Hermeneutic Philosophies of Social Science* (Amsterdam: Brill, 2016).

[6] See here with respect to philosophy of science, the discussion of the analytic-continental distinction offered in Michel Bitbol's Foreword above. Thus Heelan himself always appreciated Friedmann's reading of Cassirer and Heidegger and in this spirit, we may also note Guillermo E. Rosado Haddock, *The Young Carnap's Unknown Master* (Avebury: Ashgate, 2008).

[7] See Heelan's emphasis in his Author's Foreword, xxxiv, below.

conferences and appointments, one's work is denied publication and above all it is simply absent citation, without report or what is today called 'impact.' Heelan was always elegantly urbane about the costs involved with following his own rather than the popular truth then (and still) in vogue. Here, the price of speaking one's own truth is nowhere more in evidence in philosophy proper than in the philosophy of science.

For just this reason, it is instructive to note that Heelan by no means set this current book aside, simply leaving it unpublished in 1970 as he moved from one interest, say, to another set of interests. This book was enmired in the peer review process of the time. And why was this? Not because the mathematics or the physics was deficient, this was never claimed, nor because the scholarship was lacking, it is evident that it is not, but because it was felt that the book did not adequately survey then-new work in the philosophy of physics. In other words, and this is often the case with peer review, what the reviewers wanted was that Heelan himself might introduce changes to his manuscript to reflect other work, not all other work—Heelan already cites quite a bit—and not at all equally but one or two names that the reviewer wanted to see discussed at greater length. This is a corollary of the disciplining mentioned above: some people are to be cited and the failure to cite them can cost one a publication. Thus Heelan was told that the book was accepted, provided, so cautioned his Boston-based reviewers, that Heelan were to undertake to alter the text to reflect other readings of the philosophy of physics (in particular Shimony and Bunge, both of whom are in fact engaged in the text below). But paradigms become paradigms by means of such directives which smooth out differences, creating thereby a conventionally 'received' view.

As a physicist himself, and one who trained with the leading figures of quantum mechanics, Heelan's work in the philosophy of science is closer than most to the subject matter of the philosophy of physics. Thus Heelan could not agree to make changes because, as Heelan takes care to underline in his 1970 Preface, Heisenberg had already directly, that is to say: personally engaged the text before us, singling it out as one that resolved certain of his own puzzles and that engagement, given Heisenberg's affinity for dialogue but not less for hermeneutic reasons, could only mean that to change the text would be to sacrifice the dialogical confluence between the author-physicist himself and the physicist-subject of this work detailing nothing less than "a schema for what was 'observable in principle' and hence for what was 'real.'"

And so *The Observable* remained unpublished until now and in this form it is, as Heelan's own Author's Foreword below emphasizes, of historical scientific value. There are elements in it that will reward the attention of the reader. The most salient is the historical recollection of the conceptual-theoretical development of Heisenberg's understanding of quantum mechanics, successively considered in chapters that look at this development year by year: 1925, 1927, including Heisenberg's Chicago lectures in 1929 and culminating with Heisenberg's Gifford lectures in 1955 through 1956. There is also a valuable discussion of Heelan's own schematism for expressing Heisenberg's philosophy of quantum mechanics along with Heelan's own lattice logic, his grasp of matrices, his linguistic schemata, a more useful form of Tarski's conventional, iff snow is white with the testable (and chemically observable) example of sugar and solubility, along with Heelan's articulation of context-dependence, and some hints, valuable I think for Heidegger's philosophy of science, of "observer-cum-instrument" that is: observation of and with laboratory instruments or objects.

The later course of Patrick Heelan's intellectual trajectory shows that he admired and learned from Michel Bitbol himself and that he also held many others in high regard including Catherine Chalier, Nancy Cartwright, Bernard d'Espagnat, Martin Eger, Ronald Giere, as well as and especially, once again, N.R. Hanson as well as C.F. von Weizsäcker, Michael Polanyi, as well as Paul Feyerabend and Ivan Illich, Alasdair MacIntyre, and Bernard Lonergan. One should add the names of Marx Wartofsky and also Stephen Toulmin who was, according to Heelan, not above borrowing ideas, as well as Peter Medawar and Rom Harré, who would later be Heelan's colleague at Georgetown University, in addition to Mary Midgley and Marjorie Grene but also P. M. S. Hacker (whose work on neuroscience, with the distinguished neuroscientist, M. R. Bennett, Heelan had proposed for a session at the Eastern APA, quite against an initial resistance from some of the analytic members of the then-APA Program Committee),[8] just to name some of the more well-known names in philosophy and philosophy of science. This broad sensibility is on display in the present study, quite in spite of the historically (and at times ideologically) complicated divide in philosophy proper,[9] readers from one side or the other of so-called analytic/continental styles, will find much of interest.

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[8] The present editor was on the committee and was surprised by the opposition: Hacker is not anybody's idea of a continental philosopher if he did point out that *more* rather than less nuance was needed in cognitive science and neuroscience specifically to articulate consciousness and the mind but perhaps this critique of the limits of science is the reason she had everything she could do just to get Heelan's recommendation of this Oxford professor onto the APA program meeting in New York City in 2005 for an "authors and critics" debate with Daniel Dennett and John Searle. Mercifully, the effort was successful.

[9] I discuss this, simply because there is no way not to do so in my forthcoming contribution, Babich "Hermeneutic Philosophy of Science." In: Niall Keane, ed., *Blackwell Companion to Hermeneutics* (Oxford: Blackwell, 2015) and with specific reference too to the history of science, Babich, "Towards a Critical Philosophy of Science: Continental Beginnings and Bugbears, Whigs and Waterbears," *International Journal of the Philosophy of Science*, **24**, 4 (December 2010): 343–391.

In addition to observable objectivity, themes treated here include logic, measurement,[10] models, and consciousness as such.

In *The Observable*, Heelan draws on his formation as a physicist, including his original training in mathematics but, via phenomenology, he also emphasizes aspects that draw on practical, empirical and experimental laboratory science, and this breadth exemplifies, once again, the strengths of *continental* philosophy of science.[11] Beyond the phenomenologically attuned resources characteristic of Husserl's famed "return" to the things themselves, perhaps more valuable, at least from the perspective of an explicitly Heideggerian or even Nietzschean philosophy of science is the *questioning* (or critical) component of such an approach.

Michel Bitbol's Foreword above already points the reader to more recent studies, others of which include in addition to the importantly related collection to which he himself is a contributing editor, *Constituting Objectivity*,[12] Bitbol's own earlier essay, published in both French and English, "Traces of Objectivity: Causality and Probabilities in Quantum Physics."[13] In addition, overall, to Bernard d'Espagnat,[14] see Makoto Katsumori for a recent discussion of Bohr that also (as

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[10] See further, Stephen French, "A Phenomenological Solution to the Measurement Problem? Husserl and the Foundations of Quantum Mechanics," *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, **33**, 3 (Sept 2002): 467–491 as well as Tina Bilban, "Husserl's Reconsideration of the Observation Process and Its Possible Connections with Quantum Mechanics: Supplementation of Informational Foundations of Quantum Theory," *Prolegomena*, **12**, 2 (2013): 459–486 and Luciano Boi, Pierre Kerszberg, Frédéric Patras, eds., *Rediscovering Phenomenology: Phenomenological Essays on Mathematical Beings, Physical Reality, Perception and Consciousness* (Frankfurt am Main: Springer, 2007).

[11] Patrick A. Heelan, "Natural Science as a Hermeneutic of Instrumentation." *Philosophy of Science*, **50**, (1983): 181–204 as well as his chapter entitled "Revision of the Grammar of Reality: Readable Technologies." In: Barbara Saunders and Jaap van Brakel (Eds.) *Theories, Technologies, and Instrumentalies of Colour* (Lanham, MD: University Press of America, 2002) 117–126.

[12] Michel Bitbol, Pierre Kerszberg, Jean Petitot, eds., *Constituting Obectivity: Transcendental Perspectives on Modern Physics* (Frankfurt am Main: Springer, 2009), and see too, as Heelan himself also cites, Kristian Camilleri, *Heisenberg and the Interpretation of Quantum Mechanics* (Cambridge University Press, 2009).

[13] Bitbol, "Traces of Objectivity: Causality and Probabilities in Quantum Physics," *Diogenes*, **58**, 4 (2011): 30–57. The current editor knows that this text appears first in French *and then* again in English versions of successive issues of the same journal because she was honored to find her own essay, more on ancient philology than physics, in the very same proximity.

[14] D'Espagnat, *On Physics and Philosophy*.

its subtitle indicates) alludes to deconstruction,[15] drawing not on Heelan's physics but the literary theory of Arkady Plotnitsky (among others). An often undeveloped connection here is Heelan's reference to Heidegger's philosophic reflection on science, including the concern with consciousness and later what Heelan called "meaning-making" as both occupied his thinking toward the end of his life.[16]

Continental Philosophy: Context and Dependency

Edmund Husserl's *Philosophy of Arithmetic* first appears in 1891 and it may be argued that continental philosophy of science (and mathematics) has its inception with this publication[17] branching off from what has become today mainstream or sometimes named "analytic" philosophy of science, which may be traced to Husserl's own teacher, Gottlob Frege.[18] Husserl's phenomenology is key to Heelan's philosophy of

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[15] Makoto Katsumori, *Niels Bohr's Complementarity: Its Structure, History, and Intersections with Hermeneutics and Deconstruction* (Frankfurt am Main: Springer, 2011).

[16] See for a classic discussion of Heidegger and science, Theodore Kisiel, "Heidegger and the New Images of Science," *Research in Phenomenology*, 7, 1 (1877): 162–181 as well as more recently the several contributions, including Heelan himself to Patricia Glazebrook, ed., *Heidegger on Science* (Albany: State University of New York Press, 2012), for a recent discussion, see Thomas L. Pangle, "On Heisenberg's Key Statement Concerning Ontology," *The Review of Metaphysics*, **67**, 4 (June 2014) as well as Justin M. Riddle, "Mind/Body/Spirit Complex in Quantum Mechanics," *Cosmos and History: The Journal of Natural and Social Philosophy*, 10, 1 (2014) 61–77. Indeed, and in just such a connection, Heelan himself was very concerned, as Riddle is with entanglement. For an analytic reading that includes Heidegger together with Foucault if indeed not utterly informed by the reflections noted here, see Arun Iyer, *Towards an Epistemology of Ruptures: The Case of Heidegger and Foucault* (London: Bloomsbury, 2015).

[17] The current editor has several articles on this, see for example, Babich, "Philosophy of Science" in: Constantin Boundas (Ed.), *The Edinburgh Companion to the Twentieth Century Philosophies* (Edinburgh: University of Edinburgh Press, 2007), 545–558.

[18] See Michael Dummett, *Frege: Philosophy of Mathematics* (London: Duckworth, 1991) and Igor Hanzel, *The Concept of Scientific Law in the Philosophy of Science and Epistemology* (Dordrecht: Kluwer, 1999), especially his discussion of Michael Dummett, pp. 159ff. I thus find the discussion Michael Friedman offers in his book, *A Parting of the Ways: Carnap, Cassirer, and Heidegger* (Chicago: Open Court, 2000) to be illuminating if his focus is more neo-Kantian. I myself would want to include some of the complexities of the logical empiricists and their concerns as well as the fortunes of both world wars and indeed as I argue with respect to Kuhn, the cold war: "Paradigms and Thoughtstyles: Incommensurability and its Cold War Discontents from Kuhn's Harvard to Fleck's Unsung Lvov," *Social Epistemology*, 17 (2003): 97–107. See for a 'historical' discussion from

science.[19] For Heelan, phenomenology is indispensable for a philosophic articulation of quantum mechanics, especially for the context-dependent logic of observation he designs for this purpose.[20]

Where Thomas Ryckman and Claire Hill point to the decades Husserl spent in Halle, Heelan emphasizes the importance of the foundations of mathematics in the so-called Erlangen school, highlighting further the significance of Husserl's tenure in Göttingen. Thus Heelan's study of Husserl and Heisenberg emphasizes the crucial theoretical engagement between these thinkers and scientists as such. This same kind of collaboration is also distinctive of Heelan's own hermeneutic phenomenology of natural science.[21]

It was Einstein's famous quip, borrowed from René Descartes' *Discourse on Method*, that we do better to attend to what scientists *do* as opposed to, or rather than, what they *say they do*. Thus Richard Tieszen commends Husserl's "philosophy of mathematics" as an attempt "to do justice to mathematics as it is actually given and practiced."[22] Such a coordinate reference to the history and practice of science characterizes continental philosophy of science, an aspect foregrounded here in Heelan's *The Observable*.

For Descartes, as indeed for the entire Enlightenment order of philosophizing about cognition and perception, what the mind knows is simply mind: this Cartesian reflex is the inspiration for phenomenology as a rigorous science. Thought is to be submitted to logical analysis in order to gain knowledge of thought but the move

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the perspective of the dominant, analytic tradition in the philosophy of science, George A. Reisch, *How the Cold War Transformed Philosophy of Science: To the Icy Slopes of Logic* (Cambridge: Cambridge University Press, 2010).

[19] In addition to Heelan's 1965, *Quantum Mechanics and Objectivity* and his 1983 *Space-Perception and the Philosophy of Science*, a book on, among other things, Husserl and the metrics of vision from Luneberg to Marr, see Ryckman, *The Reign of Relativity* for an account attuned to the history of science (on Husserl and Weyl as well as Einstein, Schlick, Reichenbach, and Eddington), see too and among others, Tieszen, *Phenomenology, Logic, and the Philosophy of Mathematics* (Cambridge: Cambridge University Press, 2005) on Husserl and Gödel as well as Cantor and Brouwer, Heyting and Poincaré and as well as Feist's collection *Husserl and the Sciences*. See for an account of the influence of as well as an overview of Heelan's work in the philosophy of science, Babich, *Hermeneutic Philosophy of Science, Van Gogh's Eyes, and God*. Op cit., 1–18.

[20] See Heelan's own reference to this issue in his Author's Foreword, xxxiv, below.

[21] See Heelan, "Lifeworld and Scientific Interpretation" and Martin Eger, "Hermeneutics as an Approach to Science." Parts 1 and 2, *Science and Education*, Vols 1 and 2, 1993. This viewpoint is also to be found in Hanson, *Patterns of Discovery*.

[22] Tieszen, *Phenomenology, Logic, and the Philosophy of Mathematics*, 50.

leaves a gap, which Heelan is fond of describing as a "cut," between mind and world, thought and object. The language of "cut" is as much Bohr's as Heisenberg's.[23] As Schlosshauer and Camilieri note with reference to Heelan, "Bohr's epistemological demand for a 'cut between the observed system on the one hand and the observer and his apparatus on the other hand' also became a key theme of Heisenberg's thinking."[24]

What Eugene Wigner described as the "unreasonable effectiveness" of mathematics in the natural sciences reflects in turn any number of theoretically (not always "effectively" or "really") unbridgeable chasms. This is the traditional issue of objective vs. subjective logic for both Husserl and Heidegger and Husserl's account of intentionality sidesteps just this separation: "the intentional object of a presentation is the same as its actual object …"[25] What is known by any intentional act is the intentional object or noematic correlate, hence the *directive* direction of Husserl's classic cry, "*zu den Sachen selbst*"—"to the things themselves."[26]

Husserl's phenomenological method [*epochē*] suspends or holds in abeyance what Husserl called the "natural attitude." Via a phenomenological reduction, a properly philosophical (and not merely psychological, linguistic or scientific) reflection becomes possible for the first time, permitting a critique of reason *beyond* Kant's revolutionary Copernican turn. In properly philosophical reflection, an already given engagement of knower and known circumscribes the givenness of things to consciousness for Husserl. To this end, Husserl's account of *intentionality* recovers the scholastic and Aristotelian insight into the ideational essence of mental phenomena: the eidetic heart of consciousness as object to itself.[27] Seeking what is "immanent" in consciousness itself or as such, Husserl's phenomenological *epochē* is the necessary operation or method rendering consciousness accessible to us in its purity. It is as a "*phenomenological residuum*" that consciousness constitutes the region of being that becomes the phenomenological field.

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[23] See Heelan's emphasis in his Foreword, xxxi. And see overall Heelan, Chap. XV, below.

[24] Maximilian Schlosshauer and Kristian Camilleri, "What Classicality? Decoherence and Bohr's Classical Concepts," *Advances in Quantum Theory*, AIP Conf. Proc. 1327 (2011): 26–35, here 30. Cf. Gregg Jaeger, *Quantum Objects: Non-Local Correlation, Causality and Objective* (Frankfurt am Main: Springer, 2013) as well as Camillieri, "Constructing the Myth of the Copenhagen Interpretation," *Perspectives on Science*, **17**, 1 (2009): 26–57.

[25] Husserl, *Cartesian Mediations*, 595; see Richard Cobb-Stevens, *Husserl and Analytic Philosophy* (Dordrecht: Kluwer, 1990) John Drummond, *Husserlian Intentionality and Non-Foundational Realism* (Dordrecht: Kluwer, 1990), Robert Sokolowski, *Introduction to Phenomenology* (Cambridge: Cambridge University Press, 1999).

[26] Husserl, *Cartesian Mediations*, 146.

[27] Cf. Cobb-Stevens, *Husserl and Analytic Philosophy*; Tieszen, *Phenomenology, Logic, and the Philosophy of Mathematics*, 69ff.

Husserl's intentionality shows the objectivity of logical concepts and thus their truth. Both fulfilled and empty (intuitive and signitive) intentions are included in this account, where their objects are present or intended (*qua* absent) but amenable to an eventual fulfilment. The intentional structure may thus be said to characterize all consciousness. In Husserl's most frequently cited expression of this intentional structure, all "consciousness is consciousness of something."[28] The vital force or continuing energy of phenomenology as a contemporary research program is an ongoing elaboration of the implications of this insight. To this end, Husserl employed a method of "free" or "imaginative variation" leading to eidetic intuition of the *eidos* or essence of the intended object as indeed of the forms of intentionality (perception, memory, etc.) The eidetic analysis of intentionality, betraying Husserl's unswerving focus on truth, yields necessary, that is, *apodictic* truths.

The concept of self-evidence [*Evidenz*] for Husserl extends its Cartesian origins to the presentation of a thing directly given in an intentional experience of fulfillment or disappointment. An intuition satisfying or fulfilling an empty intention Husserl names adequation, corroborating *apodictic* truth.[29] Thus Husserl distinguished between the phenomenological description of the object or *noema* (as *noematic analysis*) and the phenomenological description of experience (*noetic analysis*), with *noesis* as the corresponding mental activity. Husserl also correlates the method of phenomenology with that of the empirical sciences. Such descriptions correspond to what we have already emphasized as regional ontologies, specific that is to the regionality of intentional concern, be that a natural scientist's concern with material objects, a biologist's or ethologist's or anthropologist's concern with living things or other human beings or our own bodily-conscious self-presence. Such ontologies include historical and social realms of culture as well as the traditional philosophic concern with the analysis of the human perception (or consciousness) of space (of Euclidean measure and habitation) and time (past, present, future), as this last was so important for Kurt Gödel.[30]

Husserl extended the concept of the life-world beyond its romantic origins to connect the worlds of science and mathematics to the world we inhabit, a project continued in Heidegger's philosophical reflections on the world view of science and technology, further revitalized in Maurice Merleau-Ponty and brought to an important contemporary expression in Heelan's work on perception, including

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[28] See for a discussion, Welton, *The Other Husserl*, 13ff.

[29] See Tieszen, *Phenomenology, Logic, and the Philosophy of Mathematics,* 61ff for further discussion.

[30] Both Palle Yourgau in his books on Gödel and Tieszen thematize this connection.

aesthetic perception, but also including theological reflection and consciousness[31] and herewith on objectivity.

In *The Crisis of European Sciences and Transcendental Phenomenology*, Husserl addressed the question of meaning, or meaninglessness, at the heart of any "rigorous" philosophy, that is: any philosophy worthy of being so named precisely in Kant's critical sense. Where Heelan's Stony Brook colleague, Donn Welton emphasizes "the process of moving through the 'positivity' of the sciences,"[32] Heelan connects this "positivist" process with the Canadian theologian and philosopher, Bernard Lonergan and one can go further to coordinate this with the empiriocritical, or Kantian modalities of Nietzsche's (and of Heidegger's) philosophies of science: whereby, as both Lonergan and Heelan would maintain, each with a different emphasis, "'pressing to a higher position from which to raise questions' is a process of 'critique'."[33] To this extent Husserl's *Crisis* refers to the "critical" crisis of the sciences and most importantly, most critically, the crisis of Western or European humanity. The extraordinary success of the Enlightenment project of the West had, in the guise of Galilean science (or what Heidegger would later speak of as calculative rationality), eliminated all questions of value from the objective sciences, that is: "all questions of the reason or unreason of their human subject matter and its cultural configurations."[34] This bifurcation at the heart of scientific reason relegated the normative and evaluative realms of the human dimensions of the life-world perforce to the irrational. Today it remains in the vulnerability of universal European culture to the imprecations of racism, consumerism, and globalization as Tzvetan Todorov suggests[35] and as theorists from Theodor Adorno to Slavoj Žižek have likewise maintained: the problem of today's scientism turns out not to be limited to academic culture alone.[36]

Following what Rickert called 'positivist" science—this would be Heidegger's "calculative," machinating/mechanistic conception of modern technological laboratory science—the crisis of modern science inaugurates the opposition

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[31] In Heelan, *Space Perception and the Philosophy of Science* in particular.

[32] Welton, *The Other Husserl: The Horizons of Transcendental Phenomenology* (Bloomington: Indiana University Press, 2002), 136.

[33] Ibid., 137.

[34] Husserl, *The Crisis of European Sciences and Transcendental Phenomenology*, 6.

[35] Tzvetan Todorov, *Hope and Memory. Lessons from the Twentieth Century* (Princeton: Princeton University Press, 2004).

[36] See Thomas Sorrell, *Scientism: Philosophy and the Infatuation with Science* (London: Routledge, 1994). It is significant that scientism persists especially as everyone (on both sides of the analytic-continental divide in philosophy but also scientists and non-scientists alike) deplores it. Somewhat, so one is compelled to suppose, like racism or sexism.

between pragmaticism and realism that still stands for many as the central problem of the philosophy of science today. Modern science limits or reduces reality to its scientifically measurable, calculable or quantifiable properties, taking reality here in the common-sense (but still and yet counter-intuitive) meaning of *scientific realism*. To this extent, for Husserl, the technological, practical, and theoretical, mathematical projects of modern science are fundamentally opposed to one another. Heidegger's *calculative* rationality *substitutes* "the mathematically substructed world of identities for the only real world,"[37] and in this way, so Husserl suggests, Galilean science itself comes to stand in the place of the world "that is actually given through perception … [that is,] our everyday life-world."[38]

The ultimate promise of phenomenology for Husserl only comes to stand in the moment of decision, the crisis of scientific reason: "Yet there he founders."[39] By means of such a stylistically Nietzschean expression of critical transcendence, Husserl emphasizes that "the world of scientific reason becomes incomprehensible."[40] And as Nietzsche himself articulates this critically transcendental turn as moments or stages of a turning in his radically truncated "history" of philosophy,[41] Husserl invokes a similarly becalmed moment, corresponding for Nietzsche to the hiatus of post-critical thought with his critically epistemic insight that, having once abolished the noumenal, we find that we have simultaneously dissolved the phenomenal. For Husserl, this point of incomprehension is likewise the point of "absolute reflection, *epochē*, the highest level of rationality."[42]

Philosophy is called upon to "think" science. And if Martin Heidegger will later insist that science is innocent of thinking, his reason for saying so turns out to be methodological to the extent that physics qua physics that is qua science "can make no assertions about physics."[43] Heidegger's objections are thus formal ones, as Thedore Kisiel has clarified what otherwise can seem to be a no more than arbitrary pronouncement: "In order to reflect on any science, it is necessary to transcend

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[37] Husserl, *The Crisis of European Sciences and Transcendental Phenomenology*, 48–49.

[38] Ibid., 5–6.

[39] Ibid.

[40] Ibid. Cf. Husserl's invocation of Nietzsche's notion of "the good European" at the conclusion of his 1935 Vienna lecture.

[41] Cf. Nietzsche, *Twilight of the Idols*, "How the Real World Became an Illusion." Nietzsche, *Kritische Studienausgabe* (Berlin: de Gruyter, 1980), Vol. 6, 80–81. Nietzsche speaks of *epochē* in his notes, highlighting a proto-phenomenological sensibility and the value of Stoic reflection to the Husserlian project of the suspension of the natural attitude.

[42] Husserl in Fink, *Sixth Cartesian Meditations*, 173.

[43] Heidegger, "Science and Reflection," 176.

that science and adopt a transcendental vantage point … in Kantian terms."[44] For Heidegger, reflecting on the foundations of his own discipline, a scientist philosophizes, with all the risks of the same, as a philosopher not as a scientist.

Thus Heidegger finds the "essence" of science inscribed as a technologically adumbrated or experimental research project. If this perspective echoes the traditional ideal of the infinite frontier of scientific progress, Heidegger also, like Nietzsche, emphasizes that the essence of research as such lies in its methodological rigor. "Rigor" thus inheres in regulatory procedural structures and institutions that guarantee the objectivity, falsifiability, and calculability of all results. These very positive scientific criteria (and we recognize the relevance of these terms for analytic philosophy of science) can be guaranteed or secured only and just because the method of scientific research as such opens up a determinate sphere of objects for investigation by projecting in advance an essential ground plan of that which is to be investigated.

Falsifiability and calculability are thus determined in the same way for Heidegger. The results of research are patently and in principle falsifiable in terms of facts. But we can now recall that and beginning with his *Being and Time*, Heidegger contends, as does indeed Dilthey and Nietzsche not less than Mach and Poincaré but also Duhem, Bergson, Bohr, Weyl, Schrödinger, and Heisenberg that what can be encountered as a fact must be determined in advance by the ground plan "sketched out" or projected or indeed "formally" indicated by the institutionalized and instrumentalized "method" of scientific research.

How is Heelan able to read the breadth of this mathematical worldview into the importance of Husserl for Heisenberg and the importance of both for the Canadian philosopher, Bernard Lonergan? And what indeed would have been the basis for the friendship between Heidegger and Heisenberg, or moving beyond the physical sciences to the social sciences, to raise the complex question of the nature and basis of Heidegger's (conflicted) friendship with Karl Jaspers, or the questions of the political in his friendship with Hannah Arendt? much less to the complex and disputed question of the relationship between philosophy and psychoanalysis (here we can add Heidegger's friendships with Jacques Lacan and Medard Boss), what can be said of the still ongoing problem of demarcation in the philosophy of science, what is 'good' and what is 'bad', what is science,

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[44] Theodore J. Kisiel "Science, Phenomenology and the Thinking of Being" in Joseph J. Kockelmans and Kisiel (Eds.), *Phenomenology and the Natural Sciences* (Evanston: Northwestern University Press, 1970), 170.

what is pseudo?[45] Only if we ask questions, including questions that would also bring us to engage the social sciences as well as the natural sciences, and that is inevitably and again, Heelan's question of meaning making,[46] once again, only if we attend to "the observable," can we hope to begin to work towards answers to such questions.

Acknowledgments

I am grateful to Patrick Aidan Heelan (17 March 1926–1 February 2015) for discussing his manuscript with me over the course of more than a decade, and for conversations that add an interval twice as long. I am also grateful to Professor Michel Bitbol for his Foreword. One could not have wished for anything more timely or more elegantly insightful. I repeat Patrick Heelan's own gratitude here on a deeply personal level for him as I also thank, likewise on his behalf, Professor Heidi Byrnes of Georgetown University for her long friendship and great kindness and for her translation of the texts by Werner Heisenberg as well as Heisenberg's colleague, Francis Zucker.

Ultimately, practically, and *sine qua non*, I thank the Rev. Liam O'Connell, S. J., Socius of the Irish of Province in Dublin, Ireland for his kindness and help in bringing this book to the light of day and I am also grateful to my department chair, Professor John Drummond for his institutional and his collegial support.

I thank too his nieces, Barbara O'Connell, Paula Bradley, and nephew, Alex Bradley, who were together with the editor herself and with Heidi Byrnes with Patrick Aidan Heelan in Dublin, during his last days at the end of January 2015, and who were as pleased as he was to anticipate this book's publication.

Riverside Drive, New York City, April 2015

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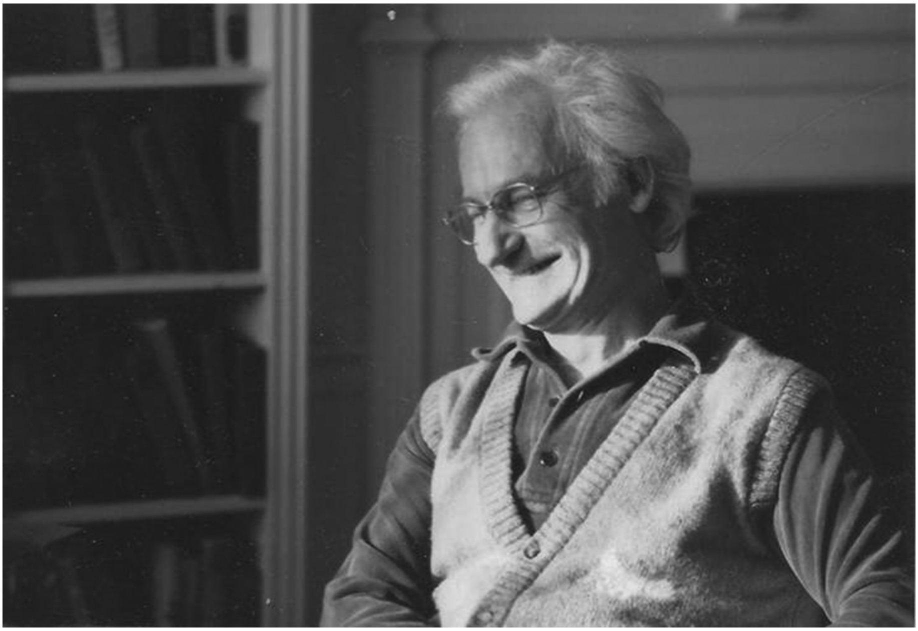
[45] Babich, "Calling Science Pseudoscience: Fleck's Archaeologies, Latour's Biography, and Demarcation or AIDS Denialism, Homeopathy, and Syphilis," *International Studies in the Philosophy of Science*, Vol. 29 (2015) 1–39.

[46] Heelan, "Quantum Mechanics and the Social Sciences" in Babich, ed., *Hermeneutic Philosophies of Social Science* (Amsterdam: Brill, 2016).



Patrick Aidan Heelan, at his home in Setauket, during the late 1970s.

Author's Foreword

My intention in this book is to probe a bit more deeply into the philosophical dilemmas posed by quantum mechanics, by tracing the path Werner Heisenberg took to make sense of what he and his contemporaries in 1927 saw as the paradoxical consequence of the Uncertainty Principle of Quantum Mechanics: it seems to require that micro-entities such as electrons, when measured, are 'observable' even though they have no precise position or kinematic trajectory in the classical space and time of mathematical intuition.[1]

But why write about Heisenberg's philosophy of science in the first place?

I initially became interested in Heisenberg because he had a philosophical concern about *the role of human consciousness* in the new physics of quantum and relativity. I wrote a book. *Quantum Mechanics and Objectivity*, and several essays on this theme. And in my personal exchanges with Heisenberg over the years, I found a man well read in the history of philosophy and interested in probing into the philosophy of science. Moreover, his focus on the role of human consciousness in quantum mechanics was clear, explicit, and well announced in the titles of two famous papers written by him, which were foundational for quantum mechanics,

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[1] See the letters of Heisenberg and Zucker (Appendix). The fact that Heisenberg was referring to the present manuscript was witnessed by his colleague Francis Zucker of the *Max Planck Institute for the Conditions of Human Life* in Starnberg, Germany.

a paper published in 1925,[2] in which he introduced quantum mechanics itself, and a second paper, published in 1927,[3] in which he deduced the Uncertainty Principles. The theme of the first paper, taken from its title, was the "quantum-theoretical *re-interpretation* of kinematics and mechanics" (emphasis added). The theme of the second paper, also taken from its title, was "the *intuitive content* of quantum-theoretical kinematics and mechanics" (emphasis added).

Both papers explicitly claimed that quantum and classical physics differed in matters related to the *functioning of human consciousness*. When observed, quantum objects became *present* in the 'world', not because they were endorsed by classical intuition but because they presented themselves *via* human action in our 'world' through measurement. Such a 'presence in our world' he called *ontological; the* 'world' he meant was a new 'post-classical world' and not the old 'objective nature' that science had previously taken to be its object of inquiry. Instead, it was the *lifeworld of human scientific culture,* as it had increasingly begun to present itself in the forms of inquiry into the subatomic world that the natural sciences had developed in the early 20th century. Such a position was consistent with the *hermeneutical phenomenology* of Heisenberg's philosopher-friend, Martin Heidegger, and with the philosophy of the Husserl circle at the University of Göttingen where the young Heisenberg taught. That it constituted a major philosophical break with assumptions that otherwise prevailed in scientific circles and, more broadly, in the intellectual debates of the time is beyond dispute.

Such considerations entered my world and became of interest inasmuch as questions regarding the connection between the quantum theory and human activity in the lifeworld had been raised as well by my former teachers, Erwin Schrödinger and Eugene Wigner.[4] It is fair to reflect on why I did not, then, write about Erwin Schrödinger or indeed Eugene Wigner who were my teachers, all the more so as they were also interested in *the role of human consciousness* in quantum physics. Wigner, though deeply committed to the view that the quantum theory of measurement implied an essential role for the human consciousness of the observer, was not a philosopher but a very intuitive physical chemist and

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[2] W. Heisenberg, "*Űber quantentheoretische Umdeutung kinematischer and mechanischer Beziehungen,*" *Zeitschr. f. Physik,* **30** (1925), 879–93; trans. in B. L. van der Waerden, ed., *Sources of Quantum Mechanics* (New York, Dover: 1967), 261–76.

[3] W. Heisenberg, "*Űber den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik,*" *Zeitschr. f. Physik*, **53** (1927), 172–98.

[4] I studied relativistic cosmology with Erwin Schrödinger at the Dublin Institute for Advanced Studies in 1946–48; and was a Fulbright Fellow in high-energy physics with Eugene Wigner at Princeton in 1960–62.

mathematician. As for Schrödinger, his interest was deeply transcendental and his religious concerns would have led me far beyond quantum physics.

All three, Wigner, Schrödinger, and Heisenberg, however, were united in their concern with the nature and meaning of the 'cut' ('*Schnitt*' in German) between the subject and the object in quantum physics. They recognized that quantum physicists, equipped with their bodily sensibility and assisted by a laboratory bench, claimed that micro-entities, such as electrons, could be 'observed' when they showed up during measurement, *despite the failure of human intuition to represent their kinematic place and motion in the space and time of the laboratory.* Today, we tend to look to cognitive science rather than philosophy for answers to problems of this sort, but in post-war Europe the crisis in quantum physics was seen as part of a cultural, philosophical crisis that was ushering in a new era, the 'post-modern' or 'post-classical era.' The new era was focused on philosophical themes and methods of philosophical research centered on *phenomenology,* or on *how human consciousness makes meanings,* and on *hermeneutics*, or on *how meanings are communicated in a community*. Among the intellectual sources for this kind of thinking were the works of Edmund Husserl, Martin Heidegger, Maurice Merleau-Ponty, and Hans-Georg Gadamer. The University of Leuven, being the home of the *Husserl Archives*, was consequently deeply involved in the new trends.

As for my own philosophical resources for tackling these problems, I brought to the task a university training in classical philosophy in which I had been deeply influenced by Bernard Lonergan's appropriation of Aquinas' appropriation of Aristotle and Plato.[5] I also brought to it an interest and inclination to venture into the new fields of *phenomenology* and *hermeneutics*. So it was not surprising that I myself had begun to be intrigued by the problems raised by Schrödinger and Wigner, but most especially by those so clearly raised by Heisenberg. Thus, when I left Wigner's Palmer Laboratory at Princeton in 1962 and moved to Leuven/Louvain, an opportunity presented itself to seek counsel on these matters from Heisenberg himself, which I did on numerous visits to him in Munich.

I had found that phenomenology and hermeneutics[6] were helpful in making sense of the distinction between classical physics and post-classical physics of relativity and quantum mechanics because these new philosophies had the capacity to explore the latent significance and function of *context*[7] in both scientific traditions;

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[5] Bernard Lonergan's major philosophical work is *Insight: A Study of Human Understanding* (Toronto: Toronto University Press, 1957 [5th edition 1992]).

[6] In the USA, the post-classical part would have been called "Continental (European) Philosophy of the post-war epoch."

[7] 'Context logic' as applied to quantum physics was a major theme of my publications in the 1970's; among them, "Quantum logic and classical logic: Their respective roles," *Synthese*,

'context' was arguably the central innovative component of these physical theories that had revolutionized 20th century physics.

Specifically, the notion of *context* can be thought of as having two parts: a part *internal to human consciousness*, comprising the functions of *meaning-making, meaning-using, and meaning-testing*; and a part *external to human consciousness*, comprising the *physical processes* associated in human life with *meaning-making, meaning-using, and meaning-testing*. The *internal part* draws on the *hermeneutic resources* of *intentionality*, which is a technical term for the making, using, and testing of meanings. These hermeneutic resources include not only the habitual practices of *categorizing* what is represented in the sensory flux, but also habits of relating groups of categories to one another by higher-order *explanatory laws* (or *theories*). The *external part of context* acknowledges the physical aspects of the *embodied practices* of meaning-making, using, and testing, such as the *organized conditions of the space and time of the laboratory bench* and engagement with the 'world' through acts of *measurement* performed by a qualified embodied observer who, in his/her community of practice, has become skilled in 'interpreting' the *measured scientific phenomenon as a datum,* present as described within the *context of the relevant categories and theories*.[8]

Such an approach to quantum mechanics turned out to be especially helpful when I approached Werner Heisenberg in 1962; he was at that time the Director of the *Max-Planck Institute for Physics and Astrophysics* in Munich. Heisenberg was interested in philosophy and was well read in the Greek and German philosophical classics as well as in contemporary German philosophy.[9] He welcomed me on the many occasions during my two years at Leuven when I visited with him at the

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22 (1970), 3–33; "Complementarity, context-dependence and quantum logic," *Foundations of Physics*, **1** (1970), 95–110. These papers were summarized and applied to binocular vision in my book, *Space Perception and the Philosophy of Science,* cited in n. 2. [The role of contextuality in quantum physics has recently been successfully explored and verified by experiments, see *Nature*, **460** (2009), 464–5 & 494–7.]

[8] See my treatment of these matters in the volume on space perception, Heelan (1983), In which I applied hermeneutic context-dependent analysis to the binocular experience of visual and pictorial spaces, and was able to show in a new way that different context-dependent data expectations can lead to different visual geometries, Euclidean or Riemannian. This evidence can be taken to support the view that the natural binocular human animal heritage enables us to intuit visually some families of curved 3D Riemannian geometries.

[9] Heisenberg contributed an essay to honor Martin Heidegger in 1959 on his seventieth birthday and his philosophy of quantum mechanics was a regular subject of summer meetings in the Black Forest with Heidegger and his intellectual friends; cf. Bibliography, Heidegger, *The Zollikon Seminars*, ed. by Medard Boss (Evanston, IL; Northwestern University Press, 2001), e.g., pp. 134–5, 246–7.

Max-Planck Institute where we had many fruitful discussions, in particular about the *context of measurement in quantum mechanics* and about his work in *elementary particle physics*.

Heisenberg's orientation towards quantum mechanics, however, was seen from the start as problematic, an assessment held on both sides of the Atlantic. It was problematic in terms of its implications for physics and just as much for its implications about deeply held philosophical positions. As for the former, Heisenberg came to see physics, and all science, as the study of the 'ontology' or 'the real' of nature. In taking that position he was fully aware that philosophical terms such as 'ontology,' and 'the real' get their meaning from the context of their use in a community of philosophical discourse. His own way of acknowledging that fact is well manifested in his essays, which took the form of conversations with his physicist colleagues in Europe that addressed the variant meanings they each gave quantum mechanics and sought out core areas of agreement within them. In the end, from his standpoint disagreements in physical theories were always disagreements about '*the real*.' This central issue about quantum mechanics for him could be captured by the question: *Can a quantum entity that is 'non-intuitable' but nevertheless 'observed' in a laboratory measurement be 'real' in the 'ontological' sense*?

But there is more to his choice of literary genre, the often surprisingly overtly dialogical essay, as the textual environment in which to discuss these complex matters. In expressing a philosophical problem as a conversational text he was well aware that no text, like no conversation, simply speaks for itself. Rather, it is the product of a particular discourse in a particular context, which involves many elements: a speaker (or writer), an intended audience, and the public linguistic practices of the community within which the textual meanings have been honed, polished, and shared. In such practices, the first recipient of the meaning is not solely the recipient, but the recipient's circle of discourse. As time goes by, however, the same text gets passed on to others beyond the original circle. One way in which this happens is by the publication of collections of already used texts—texts, that is, used by different people in different contexts of discourse. When a number of such texts are brought together in a collection, and subsequently cited from the collections, it is proper for hermeneutic reasons that the citation be accompanied by an appropriate paraphrase or commentary that gives the reader access to the original dialogical moment as related dialectically to later and re-interpreted dialogical moments. This paraphrase or commentary is omitted where hermeneutic reasons are excluded. They are excluded where the philosophy of science is based on a classical truth-functional logic of texts. However, those texts, just like measurement events in a scientific laboratory, are a social-historical event, which means they are not univocal, nor independent; instead, they are heteroglossic and hermeneutically embedded in a physical, social, and historical context.

Heisenberg's philosophical conception of *physics as an ontological science* in the sense just described was problematic as well within a larger intellectual environment comprising philosophers of science in the USA and other Anglophone countries as well as an important group of his philosophical and scientific contemporaries in Europe. Among scientific intellectuals in Europe at that time, some stressed continuity with the classical tradition in both science and philosophy, which, with Kant, took space and time to be intuitable. Others looked to the Neo-Kantians of the Marburg School, which took the categories of human thought to be practice-oriented human inventions. Finally, those who exercised the most influence looked either to the positivism of Ernst Mach, or the logical positivism, later called 'logical empiricism,' of Rudolf Carnap and the Vienna Circle. The academic discipline of the "Philosophy of Science" worldwide was largely due to the initiative of émigrés members of the Vienna Circle School. In this new orientation, it was generally assumed that a scientific text in the 'authentic' scientific tradition could speak for itself in a univocal way and, consequently, could be analyzed and questioned by any reader as long as he or she had received adequate training in mathematics and classical formal logic.[10] Few among such readers shared, much less appreciated, the subtle hermeneutic, social, and historical dimension that tempered Heisenberg's otherwise classical mode of thinking.

In turn, Heisenberg disagreed strongly with the logical empiricist approach, considering it to be an abuse of logic and, disregarding its true origin in Europe, referring to it as peculiar to "Anglophone"—meaning chiefly, to US and English—cultures.[11] Heisenberg's own cultural circle went beyond the circle of classical European philosophers. It included his philosopher-friend, Martin Heidegger, and Heidegger's circle of scientific and philosophical colleagues who met yearly in the Black Forest, as well as the circle that Husserl left behind at Göttingen. The foundational theme of this group was that no text is univocal, apart from contexts

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[10] K. Camilleri, *Heisenberg and the Interpretation of Quantum Mechanics* (Cambridge University Press, 2009). Camilleri, for example, has chronicled a vast number of relevant texts about quantum mechanics that were exchanged among European physicists in the 1920's and 1930's. As a historical work, Camilleri's book is extraordinarily useful, but as a philosophical study, it lacks hermeneutic insight into the differences in the underlying philosophical positions of the participants in his narrative. Overtly that lack of contextual insight manifests itself in the fact that he references some of the central documents of these positions in terms by their publication date in later collected works, rather than in terms of the date and circumstances of their original use.

[11] See, for example, Heisenberg's letter to Heelan, dated November 10, 1970 in the Appendix, in which he refers to his distrust of the philosophy of Anglo-Saxon writers. See my note below.

of its dialogical use by a particular community. He believed that the relevant meanings of any text are found only by negotiating one's way through the social maze of historically and socially motivated, many-voiced, and multi-contextual discourses of those who used the text in their common discourse.

He himself expressed this belief in many ways, most significantly by choosing, in line with Plato's model, the literary form of *dialogue* for his public essays. He imagined himself as participating in such dialogical conversations with his scientific colleagues as they explored the multiple dimensions of a chosen question. As these conversations followed the many hermeneutical dimensions through which the question could be brought to a focus, they would also begin to reach for the core of closed, foundational, and authoritative meanings that operated at the center of the conversational exchange. It was through such a literary genre that he sought to communicate the *exemplary contextual richness in invariance* of, in this case, quantum and relativity physics.

The text that follows dates from 1970 and reflects neither my own subsequent work nor indeed anyone else's later work. But that is because in this form it was reviewed and endorsed by Werner Heisenberg and as a consequence contributes to scholarship in the history and philosophy of science. It constitutes an unique historical record inasmuch as Heisenberg told me that he agreed with my construction of his philosophical thoughts as he tried to resolve the puzzles of quantum mechanics.

Like any historical record that is put in front of us, it reaches from the past into our present time, to which it wants to speak, and within which it wants to invite readers into a thoughtful, respectful, and insightful conversation. The passage of time since the 70's has largely becalmed the political and ideological sides of the past debate within the 'academy' and in the 'cultured world.' I hope that this opens up the possibility for exactly the kind of conversation Heisenberg favored for scientific-philosophical reflections on and inquiry into the inherent complexities of science as the foundational knowledge of nature. Through a deeply human conversational engagement with each other about the *inherent complexities of human meaning-making, meaning-using, and meaning-testing*, we might begin to see science not as an univocal 'objective' accounting provided by an 'objective' science of nature detached from any traces of human life, society, and history but, instead, as a context-dependent account and celebration of the *science of nature as part of all other forms of human knowing that is constitutive of our lifeworld.*

Georgetown, Washington, DC, September 7, 2009

Abbreviations

AHQP	*Archive for the History of Quantum Physics*, American Philosophical Society, Philadelphia. This contains documents on the history of quantum physics and taped interviews conducted by T. S. Kuhn, J. L. Heilbron and others with Heisenberg, Bohr and other quantum physicists. Reference to an interview with Heisenberg conducted by Kuhn will be made in the following way: Heisenberg-Kuhn 19 February 1963. The writer was enabled to consult this material by permission of the American Philosophical Society and through the courtesy of Charles Weiner, Director of the Center for the History and Philosophy of Physics, a division of the American Institute of Physics, New York.
APHQ	*Atomic Physics and Human Knowledge* by Niels Bohr (New York, Science Editions 1961). A collection of Bohr's essays and lectures, including "Discussion with Einstein on Epistemological Problems in Atomic Physics," reprinted from *Albert Einstein: Philosopher and Scientist*, edited by P. Schilpp (Library of Living Philosophers, Evanston, Illinois, 1949).
ATDN	*Atomic Theory and the Description of Nature* by Niels Bohr (Cambridge: Cambridge University Press, 1934). Four articles written by Bohr in the years 1925 to 1929.

CDQM	*Conceptual Development of Quantum Mechanics* by Max Jammer (New York: McGraw Hill, 1966). A very complete and well-documented account of the history of quantum physics.
MFQM	*The Mathematical Foundations of Quantum Mechanics* by Max Jammer (Reading, Mass.: Addison-Wesley, 1968).
NB	*Niels Bohr: His Life and Work as Seen by His Friends and Colleagues*, ed. by S. Rozental (Amsterdam & New York; North-Holland and John Wiley, 1967).
NBDP	*Niels Bohr and the Development of Physics*, ed. by W. Pauli (London and New York, Pergamon Press 1955).
OMP	*On Modern Physics* by Heisenberg, W. et al. (N. Y.: Collier Books, 1962).
PCN	*The Physicist's Conception of Nature* by W. Heisenberg (London, Hutchinson 1958): Three articles written by Heisenberg, plus excerpts from the works of great physicists of the past, illustrating the rise and later crisis of mechanistic philosophy.
PP	*Physics and Philosophy* by W. Heisenberg (New York: World Perspective Series, Harper & Row, 1958): The Gifford Lectures of 1955–6.
PPNS	*Philosophic Problems of Nuclear Science* by W. Heisenberg (London: Faber & Faber, 1952): A collection of eight lectures given in the years 1934 to 1948.
PPQT	*Physical Principles of the Quantum Theory* by W. Heisenberg, trans. by C. Eckart and F. C. Hoyt (Chicago: Chicago Univ. Press, 1931, reprinted by Dover, New York).
QMO	*Quantum Mechanics and Objectivity: Study of the Physical Philosophy of Werner Heisenberg* (The Hague: Nijhoff, 1965).
SQM	*The Sources of Quantum Mechanics*, ed. by B. L. van der Waerden (Amsterdam, North-Holland, 1967): A collection of some of the early important papers on the quantum theory given in translation and with a brief historical introduction and commentary.
TG	*Der Teil and das Ganze: Gespräche im Umkreis der Physik* by W. Heisenberg (Munich: Piper Verlag, 1969); trans. by A. J. Pomerans, in the World Perspectives Series, ed. by R. N. Anshen, as *Physics and Beyond: Encounters and Conversations* (New York: Harper and Row, 1971).
TPTC	*Theoretical Physics in the Twentieth Century: A Memorial Volume to Wolfgang Pauli*, ed. by M. Fierz and J. F. Weisskopf (New York, Interscience, 1960).

Preface (1970)

This work is a philosophical study of the first generation of quantum physicists. From the moment of its appearance in 1925, quantum mechanics (QM) profoundly disturbed the traditional consensus of classical physicists about what Nature is—and how different it appeared to be both in the macrocontext of General Relativity and in the microcontext of quantum mechanics. The classical consensus was that Nature was composed of a network of distinct localized elementary particles joined by determinate and mindless forces in a cosmic Newtonian Space and Time that was represented as flat and objective. Einstein's General Relativity Theory rejected the Newtonian model of cosmic Space-Time and substituted one in which local energy densities created local curvatures which functionally replaced the Newtonian concept of "gravity." Heisenberg's QM showed that the elementary particles were "quantized," that is, their matter and energy could only have definite discrete values at the most elementary level of observation and description. Schrödinger at the same time showed that matter, energy, and momentum were also governed by wave-motions which interfered with one another in Space-Time; these waves yielded on measurement only quantized matter, energy, and momentum, and in numbers only as governed by probabilities distributions.

I intend this work to be a work of critical reflection on the diversity of philosophical meanings that these terms, central to physics, had for physicists, such as Werner Heisenberg, Niels Bohr, Eugene Wigner, Paul Dirac, Wolfgang Pauli, Albert Einstein, and others. All of these European founders of quantum physics realized that the new physics seemed to overturn the traditional foundations of physics as natural philosophy founded on the intuition of Space and Time. Consequently, more than physics was challenged; also challenged were the ontologies of both classical physics and common sense. The problematic aspect seemed to focus on the differentiations of meaning attached to terms, such as "subject" and "object," "observer" and "observed," as these terms functioned in the variety of discursive frameworks used by the pioneers of QM. Questions were raised very early on about the ontology and epistemology of the new quantum science. The names of those who were early engaged in the philosophical debate about the foundations of QM and whose names will appear in this work are principally Werner Heisenberg, Albert Einstein, Niels Bohr, Erwin Schrödinger, Eugene Wigner, Wolfgang Pauli. Many others also played a role in this drama. I had the privilege of studying and conversing with three of the foundational figures of the new quantum physics: Schrödinger (1946–48 at the *Dublin Institute for Advanced Studies*), Wigner (1960–62 when a post-doc at Princeton, and Heisenberg (1962–64 in Munich while writing a dissertation on Heisenberg's philosophy of QM at Leuven, and by later exchanges of correspondence until he died in 1975).

Unlike the case of Einstein and the theory of relativity, the scientific community refused to follow the path of scientific revolution initially proposed by Heisenberg. Under Bohr's leadership, the outcome of this early social decision was (what I call) 'the paradigm[1] of complementarity.' In complementarity, irreconcilable philosophical differences were set aside, "bracketed" expeditiously to make possible a common descriptive QM language, and protocols for QM laboratory research. Unlike textbooks in classical physics, the ordinary QM textbook does not claim to be rooted in a philosophical ontology or epistemology. The QM textbook tradition is the product of a compromise that systematically suppresses those philosophical intentions—or, if mentioned, trivializes them; nevertheless, they constituted the original heuristic of its author, Heisenberg. Heisenberg's philosophy came in conflict with Bohr's; they disagreed, but their disagreements were papered over and not resolved, by the adoption of 'complementarity.' A lively discussion has since been in progress about whether this episode in the history of science should be written up as an *internalist* essay in the history of philosophy (or ideas), or as an *externalist* essay in the history of the sociology of the scientific community. Internalists, such as P. Duhem, A. Koyré, A. Crombie, E. A. Burtt, I. B. Cohen, and others, stressed the philosophical roots of scientific theories. Externalists, such as T. S. Kuhn, J. Agassi, K. Popper and a generation of younger

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[1] A paradigm is a logical set or set of rules for the use of language or set of models.

historians who grew up after World War II, are profoundly aware of the social and political aspects of Big Science. By temperament and training, the author's sympathies are with the first group.

In the case of quantum mechanics, we are fortunate in having living witnesses to its development, and thanks to the *Archive for the History of Quantum Physics* (AHQP), now at the *American Physical Society,* College Park, MD, and copies of which are on deposit in many libraries at home and abroad. This is a substantial archive of documents, taped interviews and other memorabilia on the history of quantum physics organized to enable a historian to study the origin and development of what came to be presented to the public as the 'orthodox' content of quantum theory, and as such was incorporated into the textbook tradition. Historically quantum mechanics was influenced both by the original philosophical ideas of its authors and by the sociological context in which these scientists worked. The present study then is a contribution to the current dialogue as to how the history of contemporary science should be written. Quantum mechanics, like relativity, reached its present state as the outcome of a philosophical conflict. Unlike relativity, however, the conflict was not resolved on a philosophical level. Its resolution was pragmatic and resulted in the construction of a "paradigm." As noted, a paradigm is a set of rules for the use of language or a set of models for an activity of a certain kind. Current indications point to the temporary character of such an expedient. Lacking the kind of deep-seated coherence that comes from a community of researchers unified by a shared philosophical viewpoint, basic research in quantum physics has many—one might say, too many—conflicting guides who have resurrected philosophical issues once thought discretely buried in Copenhagen. And so, this episode in the history of science is the product both of conflicting philosophies and interpersonal or social compromises.

I personally have had the privilege of studying cosmology under Erwin Schrödinger and quantum physics as a post-doc under Eugene Wigner, both Nobel Laureates in quantum physics, from whom I learnt immensely more than I could have learnt from textbooks or scientific writings alone. I have also had the profound privilege of having been able to discuss many of the topics of this book with Werner Heisenberg, also a Nobel laureate, while writing a doctoral dissertation on his philosophy of physics; he was then Director of the *Max-Planck Institut für Physik and Astrophysik* in Munich.

This study has also benefited greatly from my discussions with Professors Louis Bouchaert (Physics) and Jean Ladrière (Philosophy) of the Catholic University of Leuven/Louvain, Belgium, and with Professors Robert S. Cohen, Max Wartofsky, Abner Shimony and others of the faculty of Boston University where I spent the Fall of 1968–69, and with my colleagues of Fordham University, New York, especially D. O'Neal Vona III, Paul Brant, and Ron Champagne.

CHAPTER ONE

Observation, Description and Ontology: Strategy

My intention in this book is to study the philosophical aspects of the transition from classical physics to quantum physics—especially those that fall within the domain of ontology. Ontology is concerned with 'reality' claims, that is, with the 'Nature' that is 'represented' by the emergence of quantum mechanics. By 'reality' I mean "the world we live in"; by 'Nature' I mean "the pre-conditions of human life and society" and by 'representation' I mean the mental and other tools—particularly, the means or media of discourse—that we humans have developed to give us access to and control of Nature.

Since scientists of quite different basic philosophical commitments are able to collaborate in research, to communicate with one another and with a more general public on a wide range of scientific questions, it seems that much scientific discourse in fact is carried out on a plane that supposes or alleges to maintain the irrelevance of epistemological or ontological positions to scientific questions. Yet this would deny the relevance of the large body of writings by the founders of quantum mechanics concerned with such questions. The subject matter for this study, then, is less in the public domain of textbook exposition intended for students, than in the papers, letters, and conversations of single authors, especially of those authors who have shared their views on the nature of quantum mechanics in publicly accessible media. I have chosen to use Werner Heisenberg as the focus of this study.

Werner Heisenberg was one of the original architects of quantum mechanics.[1] His paper entitled "*Űber quantentheoretische Umdeutung kinematischer and mechanischer Beziehungen,*"[2] written in the summer of 1925, launched quantum mechanics as a new and revolutionary science. His ideas were quickly criticized by Schrödinger and Bohr, then taken up and developed by Bohr, Dirac, Pauli, Max Born and others, all of whom seemed to have brought them to completion within the span of a few years, 1925–1929. Besides his many scientific writings, Heisenberg wrote many essays of a philosophical or interpretative character; he has written his memoirs, and he has contributed many interviews to the *Archive for the History of Quantum Physics* sponsored by the American Philosophical Society.[3] All this material constitutes a *corpus* unified by the thinking of one deeply reflective man,

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[1] Werner Carl Heisenberg was born in Würzburg on the 5th of December 1901. He studied physics at Munich under Sommerfeld, Wien, Pringsheim and Rosenthal, entering the University of Munich in 1920. He was at Göttingen during the winter term of 1922–23 where he studied under Born, Frank, and Hilbert. He obtained his Ph.D. at Munich in 1923 and his *Habilitation* at Göttingen the following year. In the winter of 1924–25, he was Rockefeller Scholar at Copenhagen working under Bohr. In 1926, he was lecturer in theoretical physics at the University of Copenhagen. In 1927, he was appointed Prof. Ord. of theoretical physics at the University of Leipzig. He was awarded the Nobel Prize in 1932 and the Max Planck Medal in 1933 for his work on quantum mechanics. In 1941, he became Director of the Kaiser Wilhelm Institute, Berlin and Prof. Ord. of physics at the University of Berlin. In 1946, he helped to found the *Max Planck Institute for Physics at Göttingen*. He later became Director of the *Max-Planck Institut für Physik and Astrophysik*, Munich. [He died in 1976.]

[2] W. Heisenberg, *Zeitschr. f. Physik*, 30 (1925), 879–93. The title of the paper emphasizes "meaning-change" – "*Umdeutung*"—in mechanics. An English translation of the paper will be found in *Sources of Quantum Mechanics*, ed. by van der Waerden (1967), 261–76. The book title will be abbreviated SQM. [Also cf. P. A. Heelan, "Heisenberg and radical theoretic change," *Zeitschrift für allgemeine Wissenschaftstheorie*, 6 (1975), 113–138.]

[3] The AHQP compiled and maintained by the American Philosophical Society, Philadelphia, contains documents on the history of quantum physics and taped interviews conducted by T. S. Kuhn, J. L. Heilbron and others with Heisenberg, Bohr, and other quantum physicists. Reference to an interview with Heisenberg conducted by Kuhn will be made in the following way: Heisenberg-Kuhn, 19 February 1963. The writer was enabled to consult this material by permission of the *American Philosophical Society* and through the courtesy of the Director of the *Center for the History and Philosophy of Physics* (in 1970, this was Charles Weiner) a division of the American Institute of Physics, New York, which is a depository for the archive material. The *Archive* is presently located at the *American Institute of Physics*, on the campus of the University of Maryland, College Park, MD [and there are presently photocopy depositories worldwide].

Heisenberg, who is a scientist but also a philosophical thinker whose magisterial role in the development of quantum mechanics is undisputed.

In the early 1920's, the three problem areas of atomic physics were *spin*, the *exclusion principle*, and the *failure of the old quantum theory*.[4] Spin was a mysterious new dimension of physical objects. The exclusion principle forbade, for no clear reason, the multiplication of like bodies. The old quantum theory, so spectacularly successful in the case of the hydrogen atom, failed to account for the spectra of the helium atom or the hydrogen molecule. It was supposed that the three problem areas just *mentioned* were intimately linked: the solution of one implying the solution of all three. Although this supposition turned out to be false, the search for a new physics within the conceptual framework of classical physics gradually gave way to the belief that a radically new kind of physics would emerge. In 1923, Pauli suggested that classical physical explanations were only "classical analogues of a 'discrete' quantum theory" and that they possessed "only a symbolic sense."[5] In this case, classical physics was no more than a certain kind of model or representation of nature. The search for a radically new kind of physics that was truly descriptive of nature was under way.

The great insight which resulted in the formulation of quantum mechanics came to Heisenberg in May 1925 as he was about to leave for a vacation in Helgoland. He spent that vacation working on this new theory. In a letter to Pauli on 26 June 1925, after his return, he expressed his leading idea, "The basic principle is to consider only relations between magnitudes observable in principle, like energy, frequency, etc."[6] The same notion is repeated in the paper he published a few weeks later, the abstract of which reads: "The present paper seeks to establish

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[4] The most authoritative account of the early history of quantum mechanics is in the AHQP archive. Materials in this archive as well as other published and unpublished material are listed in *Sources for the History of Quantum Physics: Inventory and Report* [SQM], ed. by T. S. Kuhn, J. L. Heilbron, P. Forman and L. Allen (Philadelphia: Amer. Philos. Soc., 1967). Among the published sources for the history of quantum mechanics is Heisenberg's memoir: "*Erinnerungen an die Zeit der Entwicklung der Quantenmechanik*," in *Theoretical Physics in the Twentieth Century: A Memorial Volume to Wolfgang Pauli* [TPTC], ed. by M. Fierz and J. F. Weisskopf (New York: Interscience, 1960), 40–47. A comprehensive history was written by Max Jammer, *The Conceptual Development of Quantum Mechanics* (New York: McGraw-Hill, 1966), hereafter referenced as CDQM. See also P. A. Heelan, *Quantum Mechanics and Objectivity: Study of the Physical Philosophy of Werner Heisenberg* (The Hague: Nijhoff, 1965), [hereafter referenced as QMO. *Quantum Theory and Measurement* (Princeton: Princeton University Press, 1983), ed. by J. A. Wheeler and W. H. Zurek (1983) is a compilation of original material on the debate about 'measurement' in quantum theory.]

[5] Heisenberg, "*Erinnerungen usw.*," TPTC, *loc. cit.*

[6] *Ibid.*

a basis for theoretical quantum mechanics founded exclusively upon relationships between quantities which in principle are observable."[7]

At the center of Heisenberg's insight was the notion of *observability*. A large part of this study will be concerned with attempting to find out what Heisenberg meant by "a quantity observable in principle"—and with tracing the modifications that his original notion underwent.

However, why did Heisenberg think that *quantities observable in principle* were especially important in physics? The answer to this question is bound up with Heisenberg's notion that physics was a quest for a better understanding of what nature is *really* like.[8] For him, the goal and objective of physics was not primarily control or predictability or formal elegance, but the *ontology*[9] of nature in a philosophical sense. Heisenberg, who was well-read in Greek and Western philosophy in general, also collaborated in philosophical discussions on physics with such as M. Heidegger and C. F. von Weizsäcker. He saw himself as a scientist who was guided by philosophy in the critique of quantum physics, arguing in particular that Plato supports quantum mechanics over Democritus, and that nineteenth-century materialism and the Cartesian model of science are refuted by quantum mechanics. *Observability* was an important theme for Heisenberg because of its connection with the ontology of nature. In his view not every element of a theory that serves the purpose of control, prediction, or formal elegance was 'objective' in the sense of belonging to nature's ontology, but only those that are *observable in principle*. Only such observables for him had the right to play a *descriptive* role in a truly scientific account, one, namely, that described nature's *ontology*.[10]

This study, then, is a moving counterpoint on three themes: *observation*, *description*, and *ontology*. But *observation* connotes an observer and the observer's community, as well as what is observed as an object; *description* connotes a describer, a descriptive language, and community of readers. *Ontology*, however, for Heisenberg, initially meant classical objectivity in the fullest sense, an object presented in a way that is independent of human culture and history. All of these

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[7] W. Heisenberg, "*Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen*," *Zeitschr f. Physik*, **30** (1925), 879–893.

[8] I am taking the term 'reality' to be synonymous with the 'ontology of nature.' While the term 'reality' has a variety of meanings in common language, the term 'ontology' is a philosophical term and gets its meaning from the philosophical tradition in which it is used.

[9] AHQP, Heisenberg-Kuhn, 22 February 1963.

[10] In what follows, the terms "observe," "observation," "describe," and "description" connote the endorsement of what is observed and described as "real." See chapters X and XI below for a fuller discussion of these terms.

notions will be examined and criticized; they will in time become modified by Heisenberg in the course of his life—as also in the course of this study.

However, some introductory remarks are called for to alert the reader to the philosophical, cultural, and historical orientation of the author. The author initially adopts Heisenberg's own initial philosophical standpoint in favor of classical objectivity and re-plays with Heisenberg the *critical game* of which he was a player. By studying the basic strategic moves that he made, and by gradually shifting the concern from objective *description* to *language*, and then from *language* to the *describer*, this book will find the new meaning that Heisenberg eventually found for *objectivity* and *ontology*.

The initial position is Heisenberg's and it was the author's: any objective descriptive statement asserting an empirically warranted fact is a statement that belongs to the ontology of nature. Such a claim says that such-and-such is so-and-so independently of who, when, where, or why the claim is made, independently of culture and history. We need to be cautious here since it is possible that the formulation of the content, even if not the claim, might still be dependent on the activity of the subject. The kind of objectivity associated with this ontology is called "classical" or "objectifiable," and the positing of an ontology of this kind is called "objectification."[11] Heisenberg initially agrees with this usage and associates it with describing the real order.[12] He adds, however, certain restrictions: "We *objectivate* a statement," he says,[13] "if we claim that its *contents do not depend on the conditions under which it can be verified*." This restriction is not fulfilled by the quantum account of an isolated quantum system; even though such an account is "objective" (in the sense of public and inter-subjective), it is not "objectifiable," since such an account depends for its contents on the conditions and fact of observation.[14] Heisenberg and I would begin by endorsing as *real*—belonging to the *real order*—only such objective contents that are totally independent of any knowing subject. This is the kind of objectifiability that characterizes the objects of classical Newtonian and Maxwellian science and it is the sense in which this term will be used throughout this study.

I begin by making two basic kinds of critical moves. (1) The *first* is from an empirical fact to the *invariant physical context* that necessarily conditions the possible occurrence of the fact; or, in the formal mode, the move from a descriptive statement of a possible fact, say, 'A stone falls to the ground from the top of the

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[11] For example, M. Bunge, *Scientific Research II* (New York: Springer-Verlag, 1967), 171–75.

[12] PP, 130.

[13] PP, 81. Italics have been added.

[14] PP, 10; NBDP, 26–7.

Leaning Tower of Pisa,' to the *descriptive linguistic framework* within which the statement is formulated, namely, 'the stone is any stone heavy enough not to be carried off by the wind, its fall is timed by an electronic circuit that measures the time interval between release of the stone and the moment it hits the ground … and so on'; (2) The *second* is a counterpoint move from the choice of a descriptive linguistic framework back to the user of that framework, who is identically the *describer, observer, knower,* and *subject* who has set up the experiment and controls the measuring instrument and every aspect of the operation.

1) In the first critical move, a descriptive statement of fact uses certain descriptive predicates. Epistemically, no descriptive predicate functions in an isolated fashion but involves other predicates which, in turn, epistemically involve others and so on until the descriptive hermeneutical circle of descriptive predicates is closed and complete. A descriptive hermeneutical circle, then, is the complete set of semantically linked descriptive predicates that constitute the descriptive dimensions of the *heuristic program* of the subject performing the experiment, the practical meaning of which is understood by the subject and referred to as the subject's *intentionality-structure*.[15] A heuristic or intentionality-structure—we call it "A"—is the intelligible structure of a practical mode of inquiry pursued by an inquiring subject to probe the surrounding world for a particular cultural historical purpose. It is embodied in shared practical skills and common behavior patterns, and its significant outcomes are represented by a descriptive language, L_A.[16] The domain of facts attainable by a particular heuristic structure, I call "*the horizon of A*."

The *descriptive language*, L_A, then is any set of possible descriptive factual statements that represent facts attainable empirically in the horizon of A. These factual statements can be affirmed or denied if and only if the empirical and epistemological conditions are met for the valid truth-functional use of the descriptive language by the subject. The subject's world comprises a plurality of heuristic structures with their corresponding horizons. Among the plurality of horizons, some pairs are mutually discrete, some overlap partially with others, and some are totally enclosed within others. Just as every fact belongs to some horizon, it is not the case that all facts belong to one and the same horizon, so every factual

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[15] For a discussion of heuristic structures, see B. Lonergan, *Insight: A Study of the Human Understanding* (London: Longmans, 1957). The descriptive dimensions of a heuristic structure are what Lorentz calls "experiential" and "explanatory conjugates."

[16] Cf. P. A. Heelan, "Horizon, Objectivity and Reality in the Physical Sciences," *Internat. Philos. Qrtly*, 7 (1967), 375–412, and the author's *Quantum Mechanics and Objectivity, op. cit.* The notion 'modeled in language' does not mean that a language is an explicit theory of the real world. The 'theory-ladenness' of language is implicit and discovered, if at all, only on reflection.

descriptive statement belongs to one or more descriptive languages, but it is not the case that every descriptive statement belongs to one and the same descriptive language. A language then is a linguistic unit of a certain kind, and is correlated with the set of necessary and sufficient empirical and epistemological conditions for its valid truth-functional use.

Turning now to physics, a physical quantity is defined by a certain operational relation to a possible standardized laboratory environment, which includes an appropriate measuring apparatus set up in an appropriate way.[17] If the relation is to a possible but not yet actual measuring environment, the physical quantity is a *dispositional quantity*. If the measuring environment is actual, then the physical quantity is not dispositional but an *actual (or real) quantity*, and the situation justifies proceeding with a description of the measurement event. Putting the physical system into a particular kind of measuring environment does not determine what event will take place, but it does determine the kinds of events that can take place. It specifies that the outcome, whatever it is, will belong to a certain definite manifold of events for which the measurement conditions are—and *must* always be—*standard* and *invariant*. The "*must*" is both epistemological (logically necessary) and empirical (physically necessary). I stress the logical necessity, since I take the point of view that to have a physical quantity is to possess a certain logical relation to a (possible or actual) standardized environment.

Returning for a moment to the experiment of dropping stones from the Tower of Pisa, the physical milieu and the equipment remain the same, while an electronic indicator marks off the time of fall of stones of different weights as they are released from above and hit the ground below. I call the set of standard environmental, instrumental, and epistemological conditions for a particular kind of measurement "the context of the measurement"; other terms for the same thing are "conditions of observation" "experimental arrangement" or "measurement situation."

Let A be the set of standard conditions—the horizon—for a specified kind of measurement. To A, then, there corresponds a definite manifold of possible events

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[17] For a more complete exposition of this view, see Heelan (1967). Against the objection that the author is confusing "'meaning" with "testability," I reply (1) that what is meant by a physical quantity, say mass, is that it is a (possible or actual) dimension of the way objects interact with a standard environment, and (2) that in principle any physical interaction can be converted into a measuring process by the addition of a suitable communication-theoretic system to alert the scientist to the factual character of the interaction. Any interaction, then, is potentially a measurement interaction and becomes so actually when used in a communications-theoretic way. While (2) grounds *testability*; (1) grounds *meaning*, and meaning prescinds from actual measurement use, but not from potential measurement use.

E_i {E_i; i ε I (some index set)} of a set of possible measurement events. These events are the possible outcomes of Yes-No tests,[18] where, "Yes!" represents the presence and "No!" the absence of the real and actual E_i in the common horizon A. Let L_A be the minimal formal language for describing the events E_i. Then L_A is the set of elementary descriptive formal sentences constructed out of the limited linguistic resources of a set of names (or other referring expressions) for physical systems, a set of predicates for the measured quantities (numerical values) and the logical grammar of Yes/No classical logic. Let "E_i" (with quotes) be the sentence which can represent as possible or describe as actual the event E_i. Then L_A is a "descriptive language," comprising the set {"E_i"; i ε I} of sentences that are predicable under appropriate conditions. "E_i" corresponds in the formal (linguistic) mode to the physical event E_i in the material mode to which it gives a name. By "describing," then I mean the activity of representing (possible or actual) events by means of the language L_A.

The activity of describing an actual and experienced event is then an objective ontological claim about the *real presence to the real observer of what is named*. However, *what is named* has to be distinguished from the *phenomenological symbol of its presence,* which is here the change in the dial reading of the measuring apparatus. This dial change is also an event—one in the measuring apparatus—that can be experienced and can even become itself an *objectifiable event. This is not, however, the objectifiable object which is experienced and named as the 'objectifiable measured object' of the observer's measurement*, even though it is something without which the presence of the named objectifiable measured object would not be known. This problem is a complex one and will be taken up again later.

There is a plurality of event languages, L_A, L_B, etc. For each event language there is a meta-context language that describes the conditions under which they can be used truth-functionally about events in their respective horizons.[19] The *meta-context language* is then also a descriptive language, descriptive of the horizonal conditions—physical and epistemological—that justify the use of language descriptive of the kinds of events—physical and epistemological—that can happen there. A large part of the ensuing study is concerned with transpositions of

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[18] "[Yes-no tests] are observations which permit only one of two alternatives as an answer (hence the name "yes-no experiment") … for example, a counter registers the presence of a particle, within a certain region of space … Every measurement on a physical system can be reduced at least in principle to measurements with a certain number of yes-no experiments," J. M. Jauch, *Mathematical Foundations of Quantum Mechanics* (New York: Addison-Wesley, 1968), p. 73.

[19] P. A. Heelan, "Scientific Objectivity and Framework Transpositions," *Philosophical Studies* (Dublin) 19 (1970): 55–70.

linguistic frameworks in physics, and consequently will be written in what I have called "*the meta-context language of physics*."

2) The second strategic move is a counterpoint move from the choice of a descriptive linguistic framework—which is the meta-context language of choice—back to the user of that framework. The user is the *describer* (alternatively, the observer, the *knower*, or the *subject*). This is a move from object to subject, from observation to observer, from description to describer, from knowing to knower. An analysis of what is or can be described within a descriptive framework (the kinds of objects it can present) can lead to certain conclusions about the conditions or type of context necessary and sufficient for the valid use of the language. Employing a usage common to all quantum physicists, I call, the user of a descriptive language *plus the set of necessary and sufficient conditions for its use* (which I call 'its context') 'the observer.' The quantum mechanical observer then is the human subject conjoined to whatever instrument the subject chooses to use in the investigation. Sometimes the instrument is spoken of as an 'observer', even while isolated from a cadre of human observers trained to interpret the value of instrumental response and to give meaning to it. An unattended instrument can no more observe than it can describe. *Observation* entails *evaluation* and *description,* and *description* entails the valid application of an appropriate descriptive language.

Perhaps, it might be argued that the instrument does—metaphorically—'describe' its 'experience,' since it responds to a situation with signals that in themselves 'make sense' even without recourse to human intervention. They 'map' facts, and with the right physical connections, can do so univocally. The analogy between maps and language is plausible only because in fact people have constructed instruments so as to make maps a medium of meaningful communication with the scientific community. How is this possible? It will be argued below that the observer is a person conjoined by expert training to instruments not just physically but as media of communication. No one has better written about this than Hubert Dreyfus. I propose, then, in this study to use the term "observer" to signify, not the disembodied Cartesian Mind, but the *human mind embodied in the human sensory organs and in the instrument.*[20]

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[20] See chapters X and XI.

CHAPTER TWO

Relativity: Model of a Scientific Revolution

There was a special quality to the crisis which affected atomic physics in the years preceding 1925. The photoelectric effect, the anomalous Zeeman effect, the exclusion principle, the failure of the old quantum theory to account for the spectra of helium and the hydrogen molecule, all suggested to many physicists that physics was on the verge of a comprehensive change. Some predicted, not just an overhaul of the old physics, but a revolution in physics, a new general physics in which classical physics would be no more than a special piece or application. Heisenberg was one of those convinced that a scientific revolution had to take place, and that Einstein's theory of relativity[1] was already the beginning of the revolution and a model for what had to follow. What was the revolution accomplished by Einstein? And what did Heisenberg learn from it?

At the turn of the century classical physics was composed of four main departments or "closed theories"[2]—Newtonian mechanics, Maxwell's electromagnetism,

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[1] TG, 45–65, 85–100; AHQP, Heisenberg-Kuhn, 15 February 1963.

[2] The term "closed theory" used by Heisenberg (PPNS, p. 23; *Zeitschr. f. Physik*, 43 (1927), 172) reflects the influence of Hilbert and Weyl, as well as Einstein. See my comments below in Chap. IX. See also P. A. Heelan, "Heisenberg and Radical Theoretic Change," *Zeitschrift für allgemeine Wissenschaftstheorie,* **6** (1975): 113–138.

thermodynamics, and gravitational theory.[3] Each described a certain kind of system governed by dynamic laws of development in space and time.

Mechanics was given its definitive form in 1687 by Newton in his *Philosophiae naturalis principia mathematica*. Newtonian mechanics describes mass particles and continuous elastic media, and its laws are covariant[4] relative to a Galilean manifold of spatio-temporal frames (generated by the Galilean transformation group).[5]

Electromagnetism was given its definitive form in 1873 by Clerk Maxwell in his *Treatise on Electricity and Magnetism*. Electromagnetism describes charged particles and electromagnetic fields, and its laws are covariant relative to a manifold of spatio-temporal frames—Lorentz frames—generated by the inhomogeneous Lorentz group.[6]

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[3] Although gravitational theory was a part of Newton's mechanics in the sense that the *Principia* also dealt with the gravitational force, it is a separable part as the subsequent history of both mechanics and gravitational theory shows. The separate transpositions from Newtonian mechanics to relativistic mechanics, and from Newtonian gravitational theory to general relativity are each paradigmatic of that kind of scientific revolution which influenced Heisenberg.

[4] Equations are covariant relative to a certain group of transformations if they are form-invariant with respect to transformations of the group. For a study of the covariances of Newtonian and relativistic physics, see M. Strauss "Einstein's Theories and the Critics of Newton," *Synthese* **18** (1968): 251–84.

[5] The Galilean transformation group comprises (i) spatial and temporal displacements of the form: $x_i \rightarrow x_i' = x_i + a_i$ **(i = 1, 2, 3),** $t \rightarrow t' = t + t_o$; (ii) three-dimensional spatial orthogonal rotations of the form $x_i \rightarrow x_i' = c_{ij}x_j$ **(i, j = 1, 2, 3:** the dummy index is summed); (iii) uniform motions in a straight line: $x_i \rightarrow x_i + v_i t$, $t \rightarrow t' = t$. Every transformation of the spatial or temporal frame can be regarded either *passively* as a transposition from the unprimed observer to the primed observer leaving the events unchanged, or *actively* as a transposition to another set of events characterized by the primed coordinates and observed by the one untransformed observer. The importance of the latter point of view has been stressed especially by E. Wigner, "Conservation Laws in Classical and Quantum Physics," *Progr. Theor. Phys.* II (1954), 437, and in his Nobel Prize lecture, reprinted in his *Symmetries and Reflections* (Bloomington: Univ. of Indiana Press, 1967), 45. In the text I am concerned with the *passive* interpretation of space-time transformations.

[6] The inhomogeneous Lorentz or Poincaré group comprises (i) space-time displacements of the form $x_i \rightarrow x_i' = x_i + a_i$ **(i = 1, 2, 3, 4)** where x_4 is the time coordinate); (ii) three-dimensional orthogonal spatial rotations; (iii) four-dimensional orthogonal rotations, i.e., real linear transformations that leave invariant the squared space-time interval $(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2 - c^2(a_4 - b_4)^2$ separating two events whose space-time coordinates are (a_1, a_2, a_3, a_4) and (b_1, b_2, b_3, b_4). These last transformations relate two space-time frames of such a kind that the spatial part of one is moving with uniform velocity in a straight line

From the start, there was an evident and pressing problem: was there a unique, privileged, absolute space and time? Neither mechanics nor electromagnetics seemed to need such a frame except to satisfy a philosophical principle. For mechanics, any Galilean frame is a 'good frame.' For electromagnetic phenomena, any Lorentz frame is a 'good frame.' However, the Galilean manifold and the Lorentz manifold do not coincide. As long as it could be plausibly held that there was an absolute space and time which was the unique objective container of physical objects and events, it could be assumed that the overlap of the two manifolds constituted no more than the different coordinatizations of this one true frame.

The search for an absolute space and time, however, eluded all experimental attempts to determine its relation to the frames actually used in science as well as in everyday life.[7] In order to explain this puzzling phenomenon, two strategies were followed: The first, proposed by H. Lorentz and G. Fitzgerald, was to maintain the existence of absolute space and time, absolute position and absolute length, and with these, the traditional relationship of space and time with mechanics.[8] Using this strategy, the negative results of these experiments would be explained by alleging that lengths underwent apparent contraction and time intervals apparent dilation in inertial frames other than that of absolute space and absolute time, in which alone real and apparent values coincided. Such length contractions and time interval dilations were said to be the product of a relation between observers and observed objects, and this, it was claimed, belonged to the realm of the appearances of things rather than to the realm of true and objective descriptions.[9]

The second more radical strategy was that followed by Einstein. He made four proposals, which for convenience in later references I have given a numbered code:

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relative to the spatial part of the other. These transformations can be understood passively or actively. In the text I am concerned only with the *passive* form.

[7] The principal experiments to establish the contemporary scientific notion of space were done by A. A. Michelson, *Am. J. Science*, 22 (1881), 120; A. A. Michelson and E. W. Morley, *Am. J. Science*, 34 (1887), 333; F. T. Trouton and H. R. Noble, *Trans. Roy. Soc.* (London), 202 (1903), 165; F. T. Trouton, *Trans. Roy. Dub. Soc.*, 7 (1902), 379; R. J. Kennedy and E. M. Thorndike, *Phys. Rev.* 42 (1932), 400. See E. Whittaker, *History of the Theories of the Aether and Electricity: Modern Theories* 1900–1926 (London: Nelson, 1953), 27–76.

[8] Whittaker, *op. cit.* gives an excellent account of the work of H. Lorentz, G. Fitzgerald, and H. Poincaré, For a more traditional relationship between space, time, and mechanics, see A. Grünbaum, *Philosophical Problems of Space and Time* (New York.: Knopf, 1963) and his *Geometry and Chromometry in Philosophical Perspective* (Minneapolis: Univ. of Minn. Press) 1968).

[9] Cf. A. Eddington, *The Philosophy of Physical Science* (Ann Arbor, Ann Arbor Paperback, 1958), *passim*.

E1: To deny reality-status to absolute space and absolute time. This involved abandoning the classical criterion of that kind of objectivity (called "E-objectifiability" below) that was thought to differentiate (physical) reality from mere appearances; it was the filling of a determinate capsule of space for some interval of time.

E2: With respect to objectivity, he proposed to consider the covariant spatial and temporal structure of a set of physical equations as objective (in the fullest sense as describing an *ontological structure* of physical reality) and as constituting the reality of space and time. Covariance is the property possessed by a set of equations when they are form-invariant under some definite group-theoretic transpositions of spatial and temporal frames. For Newton's laws, the group is the Galilean group; for electromagnetism it is the Lorentz group.

E3: With respect to logic and meaning, he proposed to redefine the state variables (coordinates and momenta) as logically relative only to a local frame of reference.

E4: Finally, Einstein chose to claim that the unique structure of space and time relevant to the whole of physics (the issue at first concerned only mechanics and electromagnetism) was the Lorentz group which united space and time into one four-dimensional space-time. This last choice entailed a change in the laws of mechanics so as to make them covariant under the Lorentz group. These relativistically invariant laws became the new laws of mechanics.[10]

Einstein's revolutionary strategy was to take the Lorentz length contraction and the Fitzgerald time dilation to belong to the objective descriptive content of a new physics.[11] This entailed the claim that Newtonian mechanics was no more than the

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[10] These points are made in Albert Einstein's original papers, *Ann. der Phys.* ser. 4, 17 (1905): 891–921, as well as in his *Relativity: The Special and General Theory; A Popular Exposition* (London: Methuen, 1920), and *The Meaning of Relativity* (Princeton: Princeton Univ. Press, 1950).

[11] The shape of all discussion in the philosophy of science for the past forty years has been molded by the fact of the Einsteinian revolution, the first radical discontinuity in Western cosmology since the Copernican revolution. The major pre-occupation of philosophers of nature then became the foundations of knowledge. Some, like B. Russell, R. Carnap, H. Feigl, P. Bridgman, sought certainty in reduction of all knowledge to a basic set of privileged facts. Others, like J. Dewey, K. Popper, P. Feyerabend, J. Agassi, M. Wartofsky, and T. Kuhn, emphasized the ongoing character of knowledge, grounding its value in continuous criticism relative to a community of values.

description of the mere "appearances of nature."[12] By getting his revolutionary strategy accepted, Einstein brought about a revolutionary change in the description which physics gave of the structure and dynamics of the real order, implying a revolutionary transposition in the descriptive ontology revealed (or supposed) by physics.[13]

In terms of language frameworks and transpositions, let us see what Einstein's strategy proposed. Let L_N be the language in which is embodied the descriptive ontology of classical mechanics: L_N presumes that a fixed basic inertial frame—any *one* will serve—has been antecedently given. Within this frame the basic mechanical entities in the universe are described as mass particles, each possessing six independent state variables, three 'objectifiable' Euclidean coordinates (x, y, z) and three 'objectifiable' rectilinear components of velocity (v_x, v_y, v_z), all of which are, in general, functions of an independent time variable t. The descriptive ontology of classical mechanics is what Heisenberg called "the ontology of materialism," an ontology exclusively concerned with 'objectifiable' quantities[14]—quantities which, in their theoretical definition, bear no logical relation to individual observers (whether these be human subjects or the instruments they use). An objectifiable quantity, consequently, is not a function of socio-historical circumstances; it is defined neither in relation to instruments, nor to measuring processes, nor as a function of how the quantity is represented in sensation or perception; it is related, however, through the equations of the physical theory to a matrix of (similarly objectifiable) physical quantities by implicit definitions. The circle of mutually related terms constitutes a hermeneutical circle of implicit definition. In Heisenberg's language, it is a "closed theory."

Making the move from the descriptive framework L_N with its set of objectifiable quantities to the describer, we infer the general characteristics of a classical

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[12] Appearance is (conceptually) opposed to reality; but there are various forms of contrasting opposition between them, for example, phenomenon to noumenon (in Kant's philosophy), or sign-fact to signified fact (see chapter xi), or mistakenly described fact to correctly described fact, or experience described in a philosophically uncritical way to experience described critically, or experience described in an obsolete framework (e.g., phlogiston) to experience described in a scientific framework in good standing, etc. Which of these contrasts is permitted in any case will have to be judged from the context. See P. A. Heelan's "Horizon, Objectivity and Reality in the Physical Sciences," *Internat. Philos. Qrtly*, 7 (1967): 375–412 for some comments on this problem.

[13] The fact and role of scientific revolutions in the history of science is the subject of a great and growing literature much inspired by the rejection of *inductivism* and *essentialism* as philosophical positions and by a new interest in the *ecology of explanatory frameworks*. Among the authors who have written about framework transpositions are, for example, K. Popper, S. Toulmin, T. S. Kuhn, J. Agassi, P. Feyerabend, as well as W. Whewell, R. G. Collingwood, H. Butterfield, and J. Conant of the less recent past.

[14] For the sense of "objectifiable," see above, chapter 1.

observer or subject. Such an observer is one who is physically, descriptively, and culturally irrelevant to the notion of a classical mechanical object. First, the classical observer does not interact physically with the observed object; the classical object as observed and described purports to be an object antecedent to and independent of any interaction with the observer with which it may incidentally be related. Second, the subject observes by "mirroring" the object in the psychic domain of perception without contributing anything to its logical or descriptive constitution as a known object. The kind of relation between Mind (as both observer and describer) and Matter is called "parallelism," in which Mind merely acknowledges its conformity to the represented object without having contributed anything to the constitution of the object-as-known. In classical mechanics, although the state variables ($x, y, z, v_x, v_y, v_z, t$) of a system represent absolute space and time, the dynamics of the material system are represented by a set of equations among the coordinates and velocities relative to a local inertial frame. Thus, from the dynamical point of view, the (representation of a) local inertial frame works as well as the (representation of the) absolute space-time frame. This local inertial frame is the environment surrounding the object and equipped with the instruments with respect to which the represented values of the state variables are given by measurement.

There is a sense in which the environment, the instruments, and the measurement procedures can all be described in a primitive pre-theoretical language L_P that does not suppose the validity of L_N.[15] Such descriptions are often misleadingly called "operational definitions," although they are usually not strictly speaking definitions. Once a theory is entrenched in a language, the definition of a theoretical term involves the other terms of the theory through the implicit meaning relationships of the hermeneutical circle. However, an "operational definition" does not involve the other terms of the theory. At most, it plays the role of a 'bridge rule' or 'nominal definition,' which describes in pre-theoretical terms the subject matter on which the theoretical description then falls. Let us call the primitive pre-theoretical language in which the operational definitions are given L_P.[16] Now L_P and L_N will use a common spatio-temporal vocabulary but with different connotations. There are, then, two sets of spatio-temporal terms. How are these two sets of terms related to one another?

To answer this question, let us suppose that the justification of L_N is not theoretically a priori (not a rationalist position), but a posteriori to experience (an

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[15] The description, for example, which a child or somebody not familiar with the use of L_N would give of these items, would be in L_P. In this description, physical terms are mentioned, but not used in the proper sense (supposing for the moment that this is the sense they have in L_N.)

[16] By *pre-theoretical,* I do not mean prior to all theory, but prior to L_N, the language of Newtonian mechanics.

empiricist position). In this case, the real objective spatio-temporal terms belong to L_P, and L_N is just a convenient numerical representation of the a posteriori real objects in nature. These objects nevertheless have a meaning through an analogous correlation between the a posteriori entities and the measure-numbers that stand for them in L_N and indicate their a posteriori presence in the laboratory. In this analysis, terms, such as "position x," would hang ambiguously between two linguistic frameworks, in this case, between the a posteriori L_P and the a priori L_N. Convention, of course, can step in to settle the ambiguity of meaning, but it can settle the ambiguity only for conventional contexts of discourse.

Philosophical or meta-scientific discourse generally attempts to be critical of conventions. It asks not merely, what is the meaning of a term, but it raises normative questions, such as which meaning satisfies the rational goals, not just of science, but also of ontology. The interdependence of fact (as described) and norm (as to how the fact should be described if ontology is the goal) can be illustrated in the following familiar example.[17]

Consider the ordinary language sentence, "The sun rises and sets daily." Is the movement attributed to the sun real or is it merely apparent? The movement attributed to the sun is movement relative to the perception of an observer who takes the local soil as the fixed and immobile frame of reference for perceiving the everyday world. Whether or not the observer chooses to use an everyday perceptual frame as presumed by the everyday statement above rather than, say, the inertial Newtonian frame, say, of the solar system, is a matter of prudential human choice. Let us call the descriptive language L_A (*Aristotelian language*) in which the spatio-temporal terms suppose that the sun moves relative to a perceptually fixed local earthly environment. Historically, L_A was the language framework (both ordinary and scientific) used prior to the Copernican revolution. L_A enshrined the descriptive ontology of pre-Newtonian culture. Ordinary language today, however, no longer incorporates by custom and convention the spatio-temporal usage of L_A. Ordinary language has been affected by the transposition of perspective brought about by the Copernican revolution. The norm for the sophisticated use of ordinary language is now L_N. But *movement* in L_N is *movement of a mechanical system as represented and described by Newton's (numerically based) laws in the inertial frame of the solar system*. In L_N, the Sun is at rest and does not move; but in L_A the Sun

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[17] Contemporary critics of *inductivism* and hard-line *empiricism*, such as P. K. Feyerabend, J. Agassi, K. Popper, N. R. Hanson, have all criticized the principle of meaning-invariance in framework transpositions. See, for example, P. K. Feyerabend, "Problems of Empiricism" in *Beyond the Edge of Certainty*, ed. by R. G. Colodny (New York: Prentice-Hall, 1965), 145–260, and N. R. Hanson's *Patterns of Discovery, op. cit.*

moves, it "rises and sets" in its daily rotation around the Earth. The ontological commitments, in particular, of ordinary language relative to motion have undergone, it would seem, a radical change between the Middle Ages and our own day—from those incorporated in the ontology of L_A to those incorporated in the ontology of L_N. What justifies changes in the ontology of language of this kind? Are the ontological commitments of a language a product merely of historical and cultural factors?[18] Or are there other ways of thinking ontologically and epistemologically that allow for the contextual use of both old and new usages?[19]

Let us first look at Einstein. Einstein believed that two philosophical principles were involved in choosing an ontology.

1) *The first principle is that ontological assertions about nature are not validly made in any pre-theoretical language,[20] but only within the theoretical (explanatory) linguistic framework of a physical theory.*[21] Of the variety of conventionally sanctioned frameworks actually used to describe the world, in his view only one truly describes what really is the case, and that is the theoretical scientific frame. The Aristotelian linguistic frame, or what Wilfrid Sellars called the "manifest image of the world,"[22] spoke for him—as for Sellars—merely of a phenomenal realm, a realm of appearances that was destined to give way to the reality to be revealed by the correct explanatory theoretical description.
2) *A second principle is a 'principle of observability' that was for him the touchstone of the descriptive—hence, ontological—validity of a scientific theory.* However, neither Einstein nor Heisenberg, who believed he drew his inspiration from Einstein, ever fully and critically formulated such a principle.[23] It is relevant to note here that neither Einstein nor Heisenberg supported the empiricist view that a scientific theory represents either a

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[18] Cf. P. A. Heelan on "contextual logic".

[19] I mean prior to physical theories; I do not mean prior to every theory.

[20] Cf. A. Einstein, "Physics and reality" in a lecture given in 1936 and reprinted in *Out of My Later Years* (New York: Philosophical Library, 1950), 59–97, and Einstein's "Autobiographical Notes" in *Albert Einstein: Philosopher-Scientist*, ed. by P. A. Schilpp (New York: Harper Torchbook, 1959), 20–21, 48–49.

[21] W. Sellars, "Philosophy and the Scientific Image," *Science, Perception and Reality* (London: Routledge and Kegan Paul, 1963), 1–40.

[22] This point is made by Popper, Hanson, Feyerabend, Kuhn, Agassi, Lakatos, as well as by Cassirer, Whitehead, Polanyi, Lonergan and others who have written in a less empiricist style.

[23] I mean, for example, the kind of account of scientific explanation given by C. Hempel and P. Oppenheim, "The Logic of Explanation," *Philos. Sci.*, 15 (1948), 135–75, or by E. Nagel in *The Structure of Science* (New York: Harcourt Brace and World, 1961).

> generalization of pre-theoretical experience[24] or a second- (or third-) level systematization unconnected with ontological description.[25]

Convinced that L_N in its classical interpretation was incorrect, Einstein sought a new and more adequate theoretical framework for physics. In this process, his view about the epistemological and ontological value of observability developed and changed during his work on the Theory of Relativity beginning in 1905 with the Special Theory of Relativity (STR) and continuing throughout his work on the General Theory of Relativity (GTR) that began in 1915 and continued afterwards for many years.

What is relevant to our study discourse here is what Heisenberg thought Einstein meant by 'observability.' Heisenberg used the notion of observability as a foundation for what I call his 'Principle of E-observability' ("E" refers to Einstein), which Heisenberg derived, as he believed, from Einstein. Putting together the clues from his writings, I think that Heisenberg's version of this principle goes something like this: *A necessary condition for the acceptance of a scientific theory as the basis for the ontology of nature is that it does not contain an unobservable predicate; hence, all the predicates are essentially observable and describable predicates.*

To make this principle intelligible, consider, for instance, the theory of color perception and the descriptive color language based on this theory of color. The color red in this language is an *observable* and *descriptive* predicate; but is it also *essential* to the basic color language of perception? Yes! It can be! Why? Because it has been chosen to function as one of the four basic colors (six, including black and white) from which all other colors can be obtained by mixing. In this color language, all color predicates are reduced to four (or six) basic colors, among which red is a basic color and cannot be reduced to the other color predicates of the visual language. Hence red is observable, descriptive, and essential. Another example is provided by physics: energy, charge, spin, momentum are essential observable predicates for most of the basic purposes in physics. All of these are observable, describable, and essential since all are observable and describable and none of them can be reduced to other predicates in the language of basic physics.

The Principle of E-observability so expressed makes the observable, descriptive, and essential character of all predicates a *necessary condition* for the ontological status of the descriptive language of basic physics. *But it is not a sufficient condition for the acceptance of a theory as ontological*, because it can only refute a conjecture, since all it says is that a theory is not acceptable if it contains an unobservable predicate.

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[24] W. Heisenberg, "The Scientific Work of Albert Einstein," *Universitas* (English language edition), 5 (1963), 322.

[25] I mean a Baconian or Millian inductivist empiricism.

Moreover, because of *the principle of implicit definition* (that all the predicates of a theory constitute a hermeneutical circle or web of mutually related meanings), what is refuted is not the relevance of a single unobservable predicate, but the relevance of the entire theory of which the unobservable predicate is a part. Since, moreover, the meaning of a term comes from its relation to a set of other terms of the theory there can be no occurrence of a fact of observation of a disputed predicate that does not suppose the tentative acceptance of the linguistic framework of the theory.[26] Hence, the kind of observation-event that warrants a predicate as observable is a post-theoretical fact, not a pre-theoretical fact.

Einstein's conclusion from the *failure of every attempt to observe absolute motion* was that the descriptive frame L_N of classical physics lacked sufficient observational warrant. Heisenberg wrote about it: "It was at this point that Einstein stepped in and as if with a magic wand, solved all difficulties. He assumed that the bodies actually did contract in the direction of motion, and that the 'apparent' time of the Lorentz formulae was indeed the 'real' time. These formulae therefore indicated a new discovery about space and time itself, and therewith the foundation was laid for the theory of relativity."[27] Einstein on this account made the bold and imaginative move of recommending another Copernican revolution, this time to replace the Newtonian framework L_N by a new descriptive scientific framework—the relativistic framework L_R—in which in some respects the roles of "reality" and "appearance" were to be interchanged. He proposed that the "apparent" Lorentz-Fitzgerald length contraction and time-dilation were henceforth to be sanctioned as "real," and that objects described by Newtonian physics were henceforth to be accounted as "appearances." The Einsteinian revolution, when accomplished, was a revolution in descriptive ontology introduced with the aid of a new physical theory and consummated by a transformation of linguistic usage. The principle which, at least in Heisenberg's view, justified the latter transformation, I named 'the principle of E-observability.'

The ontological revolution affected also the logic or meta-logic of physical description in a subtle way. With the rejection of Absolute Space and Time—the putative home of the ideal classical observer—the role of the Universal Observer in physics was switched to that of the local observer; the coordinates (x, y, z, t) that represented the space-time of the new physics were switched to coordinates relative to the local-inertial-frame-of-reference. This now "local" observer was

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[26] Cf. E. Wigner, *Symmetries and Reflections, op. cit.*, 3–81.

[27] A. Einstein, *Die Grundlagen der allgemeinen Relativitätstheorie* (Leipzig: Barth, 1916), which is contained in *The Principle of Relativity: Original Papers*, by A. Einstein and H. Minkowski (Calcutta: Univ. of Calcutta, *1920*).

represented as an observer embodied in a local physical environment equipped with measuring instruments for x, y, z, and t, in accord with a common fixed protocol. Relativistic space was consequently also a relative space, relative, that is, logically and epistemologically to the activity of the local observer.

Some general laws, however, such as 'laws of nature'[28] do not require the specification of a particular local observer since they are true for all local inertial observers. They are expressed as equations form-invariant relative to the set of inertial observers generated by the inhomogeneous Lorentz group Λ(T) of space-time transformations. I shall call the observer that is capable of describing the set of local inertial observers the 'Universal Inertial Observer.' This is the observer-describer—or the subject—appropriate to the formulation and endorsement of the laws of nature. Since the laws of nature do not describe events but enunciate general laws which all events obey, it would seem reasonable to suppose that the logical and epistemological role of the Universal Inertial Observer is restricted to that of describing particular local inertial observers and that it does not extend to the description of events, each of which supposes some particular local inertial observer from which point of view it is described. Laws of nature then have as their describer-subject The Universal Inertial Observer, while events have as their describer-subject one of the set of particular local inertial observers.

Turning to the general theory of relativity of 1915–16, in which Einstein succeeded in uniting gravitational theory with mechanics and electromagnetics, we see the appropriate set of local observers augmented to include all those generated by the continuous group of space-time transformations from any one "good" observer that satisfied the equations of general relativity. The description of the set of such observers logically entails an abstract absolute observer—I shall call this the "Absolute Observer"—from which point of view all the laws of nature are formulated and endorsed. Particular events, as in the case of special relativity, require a local observer for their description. As in the case of special relativity, it is reasonable to suppose that the logical (theoretical) and epistemological (truth-functional) roles of the Absolute Observer is restricted to describing particular local observers, while the logical and epistemological roles of particular local observers are exercised only when events are described. The exposition just given suggests a *hierarchy of*

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[28] M. Sachs, stressing "the fundamental importance that must be given to the act of measurement" in relativity writes "it was tacitly assumed that an *outside observer* will always have at its disposal a set of measuring rods and clocks … to probe the properties of the universe (as closely as he pleases!) … [but] these investigations *did* not attempt to explicitly incorporate the measuring process into the field description of natural processes," 59, "The elementarity of measurement in relativity," in *Boston Studies in the Philosophy of Science*, vol. 3, ed. by R. S. Cohen and M. Wartofsky (New York: Humanities Press, 1968), 56–80.

describer-subjects and of descriptive-languages in physics; this implies that there is not just one universal and absolute descriptive language for all physical events, but many.

Returning to the special theory of relativity, we notice that the local inertial observer, though embodied in a physical environment and capable of interacting physically with the object to be observed and described, serves both the logical and epistemological functions of completing the definition of the local coordinate variables x, y, z, and t used in the description of an event. The physical interaction between the observer's measuring instruments and the object is taken as irrelevant to what is described. Since the measuring instrument is included as part of the observer-describer (or subject), the act of observation purports to mirror the object's relation to the inertial frame of reference without simultaneously effecting any physical changes in the object or in the frame of observation. The descriptive language of special relativity then describes an event in which the observing-describing subject makes a contribution to the logical and epistemological constitution of the event as observed and described, but not to the event as physically produced. That contributed element is solely on the level of the framework of the local inertial observer in what is described by the given description.

To summarize what occurred in the Einsteinian scientific revolution: the transposition from L_N to L_R fulfills five conditions which constitute, it seems, a sufficient set for its justification. I shall later refer to these conditions as the five conditions [Hi, Hii, Hiii, Hiv, Hv—where "H" stands for Heisenberg] of the relativistic model.

Hi: There exists a pre-theoretical language L_P (pre-theoretical relative to both L_N and L_R) which is neutral to the transposition from L_N to L_R. This includes that part of the Aristotelian language which W. Sellars calls "the manifest image of the world" in which a pre-theoretical description (in L_P) of the instruments and the measuring procedures can be given.

Hii: L_N pragmatically implies L_R but not vice versa; that is, the pragmatic adequacy of L_N in any domain implies the pragmatic adequacy of L_R in that domain but not vice versa. By "pragmatic adequacy," I mean the acceptability of a description as fulfilling the systematic and predictive goals of science when these are restricted to a sufficiently narrow domain of subject matter. The domains in question are designated unambiguously through the use of the pre-theoretical language L_P. The pragmatic condition represents one part of a *correspondence principle* connecting the old with the new physics.

Hiii: In the limiting case of the non-relativistic domain, L_N and L_R present a formal isomorphism of mathematical-theoretical structure, i.e., kinematical terms are related in the limiting case by the same theoretical relationships in L_N and L_R. This is the syntactic aspect of the *correspondence principle* connecting the old with the new physics.

Hiv: All the concepts of L_R have observable consequences. This is an ontological criterion and part of the *principle of E-observability*.

Hv: Kinematical concepts are re-interpreted as logically (theoretically) relative and epistemologically (truth-functionally) to a local observer, here taken to be embodied in an inertial frame of reference. This is a semantical criterion and included in the *principle of E-observability*.

Heisenberg came to the conclusion that the quantum theory could and should be transformed in the light of the same principles of implicit definition, correspondence, and E-observability that had revolutionized space and time and converted them into the space-time of relativity.

Quantum Mechanics 1925: Revolution

The master insight that Heisenberg obtained in May-June 1925 and that gave him the key to the new atomic physics came out of his meditations on the scientific revolution that Einstein effected by the introduction of “relativistic” space-time.[1] Puzzled by the fact that the orbital frequencies of the electron in an atom were unconnected with the frequencies of the electromagnetic radiation absorbed or emitted by the atom, Heisenberg argued that if the orbital paths and supposed frequencies had no experimental consequences, then, like the “classical” space-time that preceded “relativistic” space-time, the descriptive framework of which they were a part lacked the kind of warrant necessary to qualify as a correct description of the real quantum object. He believed that experiments in atomic physics showed that the orbital trajectories and orbital frequencies had no measurable consequences.[2]

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[1] AHQP, Heisenberg-Kuhn, 15 and 25 February 1963.

[2] B. L. van der Waerden points out in the introduction to SQM, p. 33, that Heisenberg was mistaken. A single position measurement for orbital electron can in principle be made, and also the probability distribution for a host of similar electrons can be found by measurement, but individual trajectories and orbital frequencies for low quantum numbers are not measurable (assuming, of course, a classical representation).

These considerations led him to propose what he called a "quantum theoretical re-interpretation [*Umdeutung*] of kinematical and mechanical relations."[3] He proposed to replace the kinematical framework L_N of classical mechanics by a new quantum theoretic framework, let us call it L_Q, which would fulfill the five conditions of the relativistic model. Condition Hi is satisfied by that part of ordinary and scientific language L_P which is neutral to the transposition from L_N to L_Q and includes, therefore, the language of electromagnetic theory as well as the language of the manifest image of the world. Conditions Hii and Hiii represent different aspects of Bohr's Correspondence Principle.[4] Condition Hiv states that L_Q will contain "only relations between quantities which are observable in principle."[5] Condition Hv implies that a semantical re-interpretation of the variables—a hermeneutical transformation—accompanies the transposition from L_N to L_Q.

The actual problem to which Heisenberg addressed himself in his first paper was, surprisingly, not the electronic states of the hydrogen atom, but the states of the anharmonic oscillator, a one-dimensional analogue of an atom.[6] Since his objective was not to find why classical physics failed in relation to atomic systems but *to create a new physics* for atomic systems, his opening move took the form of solving the quantum problem for a very simple atomic system. The insights so obtained could then—he hoped—be extended to more complex atomic systems.

He chose to create a quantum theory of the classical anharmonic oscillator. An oscillator of this kind is a particle which oscillates back and forth in a straight line under the influence of a non-symmetrical central force. The kind of anharmonic oscillator considered by Heisenberg was one with the following equation of motion:

$$\frac{d^2x}{dt^2} + \omega_0^2 x + \lambda x^2 = 0$$

A quantum mechanical anharmonic oscillator turned out to be, as he thought, like an atom with a discrete set of constant energy states (called "stationary states")

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[3] The original title was "*Űber quantentheoretische Umdeutung kinematischer and mechanischer Beziehungen,*" *Zeischr. f. Physik,* **30** (1925): 879–93. An English translation will be found in SQM, 261–76. Note the term "*Umdeutung*" connotes a transformation of meaning, a hermeneutical transformation.

[4] For a discussion of Bohr's Correspondence Principle, see CDQM, 109–17.

[5] Heisenberg (1925), *op. cit.*, p. 879.

[6] The case of the hydrogen atom was solved by W. Pauli, *Zeitschr. f. Physik* **36** (1926), 336–63. The English translation is in SQM, *op. cit.*, 387–615.

and which emits—or absorbs—energy in every transition from one state (E_1) to another (E_2) according to the formula:

$$h\nu = (E_1 - E_2)$$

where v is the frequency of the emitted—or absorbed—radiation and E_1 and E_2 are the energies of the two terminal stationary states of the transition. The intensity of this emission (or absorption) line is proportional to the probability of the transition between the two terminal states. Heisenberg set out to construct a new description of an atomic system which would represent the fact that only stationary states and transitions between them were qualified to play a role in the descriptive theory. He chose an array X(t) having the form of a matrix, of which a typical term was:[7]

$$X_{n,\ n-m}(t) = x_{n,n-m} e^{2\pi i\ \nu_{n,n-m} t}$$

Each row and each column of the array stood for a stationary state of the oscillator and the array elements were related to transition probabilities between the states. Within X(t), the matrix elements with large quantum numbers (i.e., with large values of n and m) were constructed so as to take on the values of the Fourier coefficients of the classical oscillator. This entailed that, with respect to frequency and intensity of emitted (or absorbed) radiation, the quantum and classical predictions coincided in the domain of large quantum numbers.

In his attempt to satisfy Hiii, he replaced the classical position coordinate x(t) by the array X(t) and (after setting up rules for the multiplication and addition of arrays) he set down the equations of development (or "equations of motion") of X(t), which he chose to be similar notationally to the classical equations of motion of an anharmonic oscillator:

$$\frac{d^2x}{dt^2} + \omega_0^2 x + \lambda x^2 = 0$$

This equation in fact is a set of simultaneous equations for the elements of the array. The formal expansion gives:

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[7] Born showed that these rules of multiplication and addition were identical with those which governed matrices. Only the rare physicist at that time was familiar with the mathematical theory of matrices. Heisenberg was not one of these.

$$\frac{d^2x_{mn}}{dt^2} + \omega_0^2 x_{mn} + \lambda \sum_{p=1} x_{mp}x_{pn} = 0, \quad m,n,p = 1,2,\ldots :$$

I shall consider three questions of special interest: (1) What was the movement of Heisenberg's thought in the creative process? What were the logical constraints imposed upon the description of this movement? (2) What was the relation between *observability* and *ontology* in this paper? (3) How was the syntactic condition (E2) of the Correspondence Principle satisfied? And, did quantum mechanics entail a semantical re-interpretation of the kinematical variables?

1. *What was the movement of Heisenberg's thought in the creative process? What were the logical constraints imposed upon the description of this movement?*

The movement of thought in the context of creative discovery, however, is very mysterious. The creation of a new hypothesis is not the product merely of logical rules. The creative process uses epistemological heuristic stratagems to generate conjectures with the hope of understanding the nature of the problem and in the process eventually to create the new revolutionary science. In Heisenberg's case, certain guiding principles were explicitly operative: the model of relativity which incorporated a principle of E-observability, a correspondence principle suggested by this, and Bohr's own version of *Korrespondenzdenken*. The principle of E-observability, as I have already pointed out, served to test conjectures, but not to build conjectures.

Heisenberg was guided in the construction of a theory by his prior conviction that the only "observable" states of an oscillator were stationary energy states. However, in the winter of 1926–27, following Heisenberg's presentation in Berlin of his thesis on quantum mechanical "Uncertainty Relations,"[8] Einstein in a conversation pressed him about the epistemological grounds on the basis of which he claimed that *even before the explicit formulation of his quantum theory of matrix mechanics* he claimed there were *observable* stationary energy states. Einstein, having by this time repudiated the Machian background which influenced him in the construction of the special theory of relativity, was unhappy with what the seemingly positivistic language of Heisenberg's paper, and he attributed Heisenberg's insistence on "observables" to the influence of a Machian kind of positivism. Heisenberg seemed to be claiming that even prior to the conjectured theory, he (Heisenberg) knew and was able to observe and describe stationary energy states. Einstein objected that the theory with logical necessity came first, and

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[8] AHQP, Heisenberg-Kuhn, 15 February, 1963; TG, *op. cit.* 85–100.

observability could only be claimed subsequently as a consequence of an already established theory.

It is not unlikely that Heisenberg—unaware of the subtle epistemological aspects of Einstein's question—seemed to make the claim Einstein attributed to him. In his conjecture that he had had the correct insight, Heisenberg might have thought that all he had done was to systematize observables that were already at hand but only pre-theoretically, on the uncritical inductivist notion of scientific method that was nevertheless endorsed by many scientists of a positivistic complexion. Moreover, Heisenberg's criticism of those who seem to turn physics into a mathematical exercise, and his account of himself as a physicist who first seeks the "physical solution" and then tries to fit a mathematical theory to it,[9] might have given the impression that he endorsed a positivistic notion of science. However, he has always strongly and explicitly opposed any attempt to enlist his support for positivism and by temperament, and (certainly later) by choice, Heisenberg was more in sympathy with Platonism than with the positivism or operationalism, which have claimed him on the basis of some of the phrases he used.

As an aside, one might query whether at least at the start Heisenberg intended the term "stationary energy state" to take its meaning from the resources of the pre-theoretical language L_P rather than from the conjectured new theory L_Q. Certain pre-theoretical facts do remain description-invariant in the transition from L_P to L_Q, such as the pre-theoretical description of the localized signals of measuring instruments and the classical treatment of electromagnetic pulses. But Einstein was not speaking to Heisenberg about these but about his use of the term "stationary energy state."

Let us be clear about the epistemological problem involved in this story. What was the meaning of the term "stationary energy state' for Heisenberg before his new revolutionary but conjectured theory had gained the authority of an entrenched descriptive scientific language? Was it merely a short-hand metaphorical way of referring to the progenitor fact in L_P that subsequently became the "stationary energy state" in L_Q? Or did it refer to a merely conjectured fact arising out of the use of the new conjectural descriptive linguistic framework L_Q? The most likely answer, again, is that Heisenberg was not fully aware of the subtle epistemological points made by Einstein. The title he chose for his first paper, however, throws some light on how he was thinking: "On the quantum mechanical re-interpretation of kinematical and mechanical relations." This, plus the role mathematical theory played in his view of the world, suggest that *Heisenberg accepted the definitory role of theory*

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[9] AHQP, Heisenberg-Kuhn, 22 February 1963.

in observation right from the start and that, therefore, he was in basic agreement with the Einstein's later point of view.

Also we do know that Einstein seems to have been satisfied by the answers he received from Heisenberg in Berlin in the winter of 1925–26.

2. *What was the relation between observability and ontology in this paper?*

It was part of Einstein's belief, shared by Heisenberg, both of whom were strongly imbued with the Platonic tradition, that mathematical structure was the ultimate measure of the real. Not merely was the real order mathematically structured but, given a correct theory, the totality of mathematically representable situations was identified with the totality of real situations.[10] The new quantum theoretical kinematical variable X(t) was so constructed that it contained just those mathematical structures that, suitably interpreted, were thought to have measurable consequences and no more. It was constructed to provide a schema for what was "observable in principle" and hence for what was "real."

Note first of all the abstractness of this notion of observability. The fact that an emission (or absorption) of a certain frequency has taken place is registered by means of a localized space-time signal in some piece of apparatus that is describable in pre-theoretical terms. What is emitted (or absorbed) is described in classical electromagnetic terms. The fact of emission (or absorption) is interpreted through the quantum theory as representing a transition from one stationary energy state to another. Note how the (pre-theoretical) signal, the classically described emission (or absorption) and the existence of quantum mechanical stationary states are all observable, but *each fact is described in a different language and each is observable in a different sense.*

Finally, *in the context of Heisenberg's original paper, "observability" had its most abstract sense when predicated of the stationary states; this sense I have called "E-observability."*

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[10] Heisenberg, "Quantum theory and its interpretation," in NB, 94, 105. AHQP, Heisenberg-Kuhn, 19 and 25 February 1963, and 5 July 1963. Heisenberg also justifies the logical role of thought-experiments on this ground. The use of thought-experiments was a common practice in the early days of the quantum theory. Heisenberg recalls how the explicit formulation of this principle came to him one day in the winter of 1926–27 when he was running in the Faelled Park in Copenhagen. AHQP, Heisenberg-Kuhn 5 July 1963. This is also mentioned in NB, 105.

3. *How was the syntactic condition Hiii of the Correspondence Principle satisfied? And, did quantum mechanics entail a semantical re-interpretation of the kinematical variables?*

The new kinematical variable X(t) was in the most abstract sense of the term observable. The syntactic aspect of the correspondence principle was, namely, that kinematical terms be related in limiting cases by the same theoretical relationships both in L_N and in the new linguistic framework. This imposed another condition that was harder to fulfill. The principal reason for this is that it was not clear to Heisenberg how the new kinematical matrix variable X(t) was related to the old classical continuous variable x(t). Even the authors of the *Drei Männer Arbeit*[11], which presented quantum mechanics in a very sophisticated way, professed ignorance as to how the symbolic geometry of quantum mechanics was related to the visualizable geometry of classical mechanics. Even after many decades of discussion, the relationship remains obscure.

X(t) simultaneously contained a representation of both large and small quantum numbers. To become algebraically isomorphic with x(t) in any domain, X(t) would have to take the form x(t)I, where I is the unit matrix. This does not happen as long as h is not zero, since the rows and columns representing the small quantum numbers are always present in X(t). The syntactical form of classical dynamical equations and their solutions can be retrieved only if h is put equal to 0. Assuming that this is the way Heisenberg chose to fulfill the syntactical correspondence condition Hiii, the question arises: what light does this throw on the semantic connection between the new kinematical variable X(t) and the classical kinematical variable x(t)?

Heisenberg's intention was quite clearly to construct a new variable called, like the old, "the position of the system," and one descriptive of the individual atomic system. The new quantum mechanical variables were not intended to be ensemble variables in the sense in which, in the Kinetic Theory of Gases, say, temperature and entropy are variables which are predicated of the collectivity, but not of individual molecules of the collectivity. Quantum mechanical variables, like position, momentum and energy, were intended to be descriptive of individual atomic systems. Moreover, Bothe and Geiger, by coincidence, showed that in measurements of the Compton scattering of a photon by an electron the

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[11] The "*Drei Männer Arbeit*" is the name used by Heisenberg to designate the paper written by M. Born, P. Jordan and himself: "*Zur Quantenmechanik II*," *Zeitschr. f. Physik*. **35** (1925): 557–615, An English translation is in SQM, 321–85; the text reference is on page 322.

momentum and energy conserved belonged to individual atomic processes and not just to a large collectivity of such processes as was once proposed by Bohr, Kramer, and Slater.[12] Subsequent experimental work as, e.g., on scintillation phenomena, on weak beams, etc., supported the view that quantum mechanics describes individual systems.[13]

On the other hand the way in which X(t) was constructed suggests a reference to an ensemble. It contains a scheme of all definite energy states possible for a system, with coefficients from which to calculate the transition probabilities between those states. X(t) could be said then to describe a statistical ensemble of transition events between the states represented within the operator X(t).

Perhaps there is an analogy with temperature after all, considering not the molecules that make up the collectivity, but the collectivity as a whole to which the descriptive variable, temperature, applies. A peculiarity of temperature as a descriptive variable is that it can be predicated of an individual system only in so far as this system is a member of a canonical ensemble of like systems. In a canonical ensemble each system has a definite energy, but the energies are distributed according to a canonical probability distribution. Thus, an individual system, in so far as it has a temperature, is treated as a virtual ensemble; that is, as a random sample of one taken from a canonical distribution. The quantum mechanical variable X(t) has much in common then with such a notion as temperature: it is predicated of a single individual but only in so far as the individual belongs to a canonical ensemble, in this case, of systems undergoing transitions. Underlying the notion of temperature, however, is a molecular model where every system is a collectivity and the variables of the individual molecules comprising the collectivity constitute a set of micro-variables which "explain" thermodynamic laws and why the canonical distribution is of a certain kind. Whether in the quantum mechanical case, an analogous set of "hidden variables" exists to "explain" quantum mechanical laws and probability distributions, was soon to become one of the most important issues in atomic physics.

Supposing,: then, that a quantum mechanical variable, such as "position" or "energy" refers to a single atomic system through the notion of a virtual ensemble,

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[12] The experiments of Bothe and Geiger demonstrated individual energy conservation in the subatomic domain Cf. NB, p. 104. A discussion of the experiments, together with the references, is found in CDQM, 185f.

[13] A. Landé has frequently stressed this point, for example, in his "*Dualismus, Wissenschaft and Hypothese,*" in *Werner Heisenberg und die Physik unserer Zeit,* ed. F. Bopp (Braunschweig, Viehweg 1961), and in his *From Dualism to Unity in Quantum Physics* (Cambridge: Cambridge Univ. Press, 1960).

it becomes important to ask the question: are such terms as "position of the system" or "energy of the system" meaning-invariant in the transition from classical to quantum mechanics?

There are many reasons for supposing that the quantum mechanical variable X(t), "the quantum mechanical position of a system," is different in meaning from the classical position variable x(t). As Born was soon to show, X(t) does not commute with its conjugate momentum variable $P_x(t)$. The set of quantum mechanical variables (X, Y, Z, P_x, P_y, P_z, H[energy]) are not independent variables as in the classical case, but are connected by a set of commutation relations:

$$-[tH - Ht] = [XP_x \text{—} P_xX] = [YP_y - P_yY] = [ZP_z - P_zZ] = -ih/2\text{л}$$

with every other pair commuting. By the *principle of implicit definition*, this set of variables could not be meaning-invariant with respect to the transition from classical to quantum mechanics, that is, if the convention is adopted of defining physical quantities through their theoretical relations.

If that convention is not adopted—and whether or not it is adopted is an empirical fact—then there are grounds for affirming a continuity of meaning in the fact that they share the same pre-theoretical (or operational) basis. The same elementary operations that measure x(t) (e.g., coincidence measurements using a rigid rule) also measure X(t): the same that is, relative to a pre-theoretical description. This kind of "pragmatic" continuity constitutes that aspect of the correspondence principle enunciated under condition Hii. However, such a "pragmatic" continuity in the use of the variable with continuity of meaning would usually be only a temporary phenomenon, as the thrust of scientific explanation is to recommend the eventual adoption of the theoretical meaning as the true descriptive meaning.

At least part of the difficulty in explicating the sense of X(t) was due to the inadequacy of the model which Heisenberg chose to follow. The syntactic correspondence condition Hiii, for example, is not a sufficient guide unless accompanied by semantical rules which state how the interpretation of the new formalism is related to the interpretation of the old. In the passage from classical space-time to relativistic space-time, the corresponding semantical rules were clear. But in the passage from the numerical variables x(t) to the array X(t), more radical changes were effected in the semantical rules but what these changes were was not clear and they were not expressed.

The uniqueness of Heisenberg's quantum mechanics was soon to be challenged by the publication of another quantum theory—Schrödinger's wave mechanics.

Wave mechanics was the product of quite a different heuristic structure, and was expressed in quite a different set of descriptive terms. In relation to the relativistic model of a scientific revolution, Schrödinger^{t}s wave mechanics satisfied conditions Hi, Hii, and Hiii. It did not differ from quantum mechanics in relation to Hv. Heisenberg held, probably with good reason, that it could not be made to satisfy condition Hiv of observability.

CHAPTER FOUR

Wave Mechanics 1926: Reaction

The publication in 1926 of Schrödinger's wave mechanics, a rival form of the quantum theory, was a challenge not merely to the matrix formalism of the new quantum theory but to the philosophy behind it.[1] Schrödinger had constructed a theory based upon continuous field variables, like Maxwellian electromagnetic theory, in which the point particle electron was replaced by a wave group. In this, he was following out a line of thought first suggested by L. de Broglie. Schrödinger's leading notion was the representation of the atomic system by a continuous wave function which satisfied a differential equation of motion that was later called the "Schrödinger's equation" of the system. It was a wave (or field-) theory of matter. Heisenberg's was in some sense a particle (or localized) theory of matter that by contrast stressed discontinuity and the isolated character of stationary states, and did so by constructing a matrix representation of the mechanical variables (or "observables"). The matrix formulation was better adapted to the treatment of stationary states, while Schrödinger's wave formulation was better adapted to the treatment of non-stationary states of a system. Schrödinger wrote to show that an isomorphism existed between the formal mathematical aspects of the two theories.[2]

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[1] For references and a historical account, see CDQM, sect. 5.3.

[2] E. Schrödinger, "*Quantisierung als Eigenwertproblem*," *Annalen d. Physik* IV, series 79 (1926): 734–36. An independent proof was given by C. Eckart, *Phys. Rev.*, 28 (1926): 711–13. For

From the start, Schrödinger's theory was highly successful, moreover, it conveyed an intuitive picture of atomic phenomena that was easy to grasp, and it used elegant, sophisticated, classical mathematical forms. Heisenberg's criticism of wave mechanics was based on the observability principle: wave packets, he argued, are not observed—what are observed are quantum jumps (discontinuous transitions between states).[3] Moreover, he argued that the 3n-dimensional wave function for an n-particle system was unobservable in principle since real space has only 3 dimensions. He also showed that Schrödinger's wave function—except in some special cases—would spread with the passage of time, so that given sufficient time, a free electron would be unlocalizable.

In defense of the wave theory of matter, however, Schrödinger could appeal to the observable fact of interference patterns between electrons and α-particles. But that eventually raised the question of how the interference pattern was built up. Heisenberg, following the Born-Pauli interpretation of the wave function, contended that it was built up out of a multitude of localized point-like impacts statistically distributed in an extended pattern. Schrödinger, however, held it was the direct manifestation of the extended wave-like character of individual electrons or α-particles. It was suggested that the matter could be settled by using very weak beams of virtually isolated particles, but at that time such experiments were not technically possible. Moreover, what one "observed," whether wave or particle, was a function of what theory one held, for the scintillation or silver grain on a photographic record was not the atomic particle itself but merely a record of its passing. Heisenberg's passionate opposition to Schrödinger indicated how much he was motivated by an a priori philosophical conviction stronger than the a posteriori quality of the physical evidences.

A meeting between Heisenberg and Schrödinger was arranged by Bohr at Copenhagen in September 1926 to discuss their differences. Although the outcome of the meeting was to confirm the two principal antagonists in their opposing points of view, Bohr became convinced that the two representations—the

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a discussion of the logical aspects of equivalence, see N. R. Hanson, "Are Wave Mechanics and Matrix Mechanics Equivalent Theories?," in *Current Issues in the Philosophy of Science*, ed. by H. Feigl and G. Maxwell (New York: Holt, Rinehart and Winston, 1961), 401–425. Hanson denies that the two forms of the quantum theory are semantically equivalent.

[3] Heisenberg's criticisms of wave mechanics are summarized in retrospect in his "*Erinnerungen, usw*," TPTC. Originally they were incorporated in "*Mehrkörperproblem and Resonanz in der Quantenmechanik*," *Zeitschr. f. Physik*, 38 (1926): 411–26; "*Schwankungserscheinungen und Quanten-mechanik*," *Zeitschr. f. Physik*, 40 (1927): 501–506; "*Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik*," *Zeitschr. f. Physik*, 43 (1927): 172–98; and in his PPQT. See Jammer CDQM, *op. cit.*, 272.

continuous and the discontinuous—were useful, and that—in some sense not yet clear—each touched on something valid with respect to the physical core of the real world.[4]

The most formidable argument against matrix mechanics was its non-intuitive character. The scientific objects it alleged to describe were non-Newtonian objects, incapable of satisfying the Kantian axioms of intuition, the anticipations of perception, the analogies of experience, and the postulates of empirical thought which, either as a matter of fact or, as Kant would hold, with necessity, characterize empirical scientific phenomena.[5] Quantum mechanical objects seemed to have unfamiliar and extremely strange ways of being represented in the field of human intuition; they were nothing like the familiar items of furniture which share our world with us. Schrödinger made this the thrust of his attack on Heisenberg's theory[6]—that it left people wondering whether it was necessary to depart so wrenchingly from the familiar, tried and tested criteria of human experience.

In his counterattack Heisenberg charged that Schrödinger contradicted proven experimental results. He also recognized the force of the argument that "so horrendous and abstract" a theory as quantum mechanics, and one "so opposed to our intuition of what nature is like" as Schrödinger described it, could hardly be a valid physical theory.[7]

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4 N. Bohr, "*Die Entstehung der Quantenmechanik*" in *Werner Heisenberg und die Physik unserer Zeit*, ed. by F. Bopp (Braunschweig: Viehweg, 1961), ix–xii. See also Jammer CDQM, *op. cit.*, 324.

5 Cf. I. Kant, "Transcendental Analytic" in The *Critique of Pure Reason*; in Kemp Smith's translation (London: Macmillan, 1963), 102–297. In the *transcendental analytic*, Kant deduces the conditions of possibility of a scientific empirical object (for him, a Newtonian object) which he calls the synthetic principles of pure understanding, viz., the 'axioms of intuition,' the 'anticipations of perception,' the 'analogies of experience' and the 'postulates of empirical thought.'

6 See CDQM, 272 where the reference is given.

7 Quoted by Heisenberg in *Zeitschr. f. Physik*, 53 (1927), footnote 195.

CHAPTER FIVE

Search for a Paradigm

Throughout the early part of 1927, Heisenberg and Bohr, each in his own way, tried to provide an intuitively satisfying foundation for the quantum theory. This was more a psychological or psychosocial one than a philosophical one. Heisenberg's approach from the start had been in the Western tradition of the philosophy of nature that was based on a search for the ideal core of human experience. The psychological or psychosocial problem which now dominated the situation was a different one. It might be described as a search for a new *scientific paradigm*.[1] A paradigm is a set of models for scientific investigations of a certain kind, models that serve to apprentice a newcomer to the art of scientific investigation by having him re-do, in fact or demonstration, the basic experiments in the field. A paradigm then is more than a set of objective scientific laws or a set of explicit experimental instructions. It consists in habits of thinking, feeling, and acting engendered in a member of the scientific community by having been apprenticed to that community, by having used approved text books, by having come to understand scientific

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[1] The term "scientific paradigm" was introduced by T. S. Kuhn in his *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962). The precise meaning of this term in Kuhn has been disputed by many philosophers. I wish to bypass this discussion and take its meaning to be simply descriptive as an *exemplary and institutionalized scientific method*.

theory sufficiently to solve the set of standard problems which play the role of model objective scientific investigations for this community. A paradigm then is a certain quality of a social context in which esthetic norms and traditions combine with explicit rational norms in the carrying out of a scientific investigation. What was most urgently needed, once quantum mechanics had shown its power was to create a community paradigm of quantum theoretic research.[2]

The old quantum theory was such a paradigm; it stimulated and sustained an immense amount of fruitful collaboration and research even though it did not contain a descriptive ontology of atomic systems. One of the principal reasons for dissatisfaction with the old quantum theory was precisely that it neglected the descriptive ontology of atomic physics. On the one hand, it did not depart from a basic classical ontology of particles and fields while, on the other hand, it added ad hoc rules for quantum phenomena which were incompatible with ontological description of these basic entities. Heisenberg attempted to address this problem in a paper to which he gave the title: "On the intuitive content of quantum-theoretic kinematics and mechanics".[3] The purpose of the paper can be inferred from the following passage explanatory of the title: "a physical theory can be intuitively understood when we can think qualitatively in all simple cases about the empirical consequences of this theory and when we know simultaneously that the application does not involve internal contradictions."[4] While the latter phrase recalls Heisenberg's mathematical criterion for the ontology of nature, the former, with its use of terms, such as "qualitative" and "all simple cases," implies that the intuition involved is not a philosophical intuition into the ontology of quantum mechanical systems, but a kind of "feel" for experimental research in the quantum mechanical domain—a communion in a paradigm of research. The intuition in question might be described as one into the conditions of possibility of our becoming sufficiently familiar with these strange objects of quantum mechanical research as to be able to communicate with one another about them and to predict events in which they take part. A paradigm in this sense is concerned with useful ways of conceiving, imagining and speaking about a certain class of events. It is not

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[2] The view that Heisenberg's original picture and Schrödinger's picture were so incompatible that any amalgamation of the two must be conceptually superficial was shared by N. R. Hanson and (citing Hanson) P. A. M. Dirac. See N. R. Hanson, "Equivalence: The Paradox of Theoretical Analysis" in *Mind, Matter and Method*, ed. by P. K. Feyerabend and G. Maxwell (Minneapolis: University of Minnesota Press, 1966), 427, n. 2.

[3] Heisenberg (1925) *op. cit*. For a detailed discussion of its contents in English, see Jammer CDQM, *op. cit*. section 7.1. In his published "*Erinnerungen …*" TPTC, *op. cit.* Heisenberg recounts that the contents of the paper were worked out in collaboration with W. Pauli.

[4] Heisenberg (1927c) *op. cit*. 172.

descriptive of the ontology of the events in question, and its use is justified merely on pragmatic grounds.

The intertwining of this important but seemingly parascientific aim with Heisenberg's more fundamental interest in the philosophy of nature, helps to explain certain simplistic features of the paper, such as its return to classical descriptive language and its explanation of position and momentum uncertainties by the perturbing effect of a classically described measuring process.[5]

It also explains why opinions on the importance of the paper have differed so widely. B. L. van der Waerden does not even include it in his collection, *Sources of Quantum Mechanics*. Pauli, on the other hand, prized it highly and largely through his influence, it played an important role in the development of the text book tradition of quantum mechanics. It is also considered fundamental in quantum mechanical measurement theory.

Bohr was unhappy with the paper: he thought it dealt too exclusively with the discontinuous spectra of atomic variables, quantum jumps, and the particle-like manifestations of atomic systems.[6] In deference to Bohr, Heisenberg added a note in which he calls attention to Bohr's interpretation, that claimed a continuous wave interpretation as another possibility, and consequently that for Bohr an adequate intuitive understanding involved (what Heisenberg called) "a strict dualism of wave and particle,"[7] one that used both pictures jointly in the paradigm.

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[5] This is said on the authority of Jammer CDQM, *op. cit.*, 333.

[6] Heisenberg "*Erinnerungen* …," TPTC *op. cit.* Also AHQP, Heisenberg-Kuhn, 25 February 1963.

[7] AHQP, Heisenberg-Kuhn, 5 July 1963. Heisenberg stated that he, on the other hand, favored an either-or dualism in which every problem could be worked in either picture.

CHAPTER SIX

The Uncertainty Relations: Paradigm or Ontology of Nature?

Is it possible to infer which of the elements of Heisenberg's interpretation he held to belong to the basic descriptive ontology of quantum mechanics and which formed merely a part of a proposed paradigm? According to his own account,[1] it was not until some months after the paper on the Uncertainty Relations was written, that he abandoned the belief that the old classical descriptive concepts were inadequate for quantum physics. I surmise then, that in that 1927 paper classical visualizable pictures of quantum phenomena were intended to belong merely to the paradigm and not to the underlying ontology. I conclude then that the underlying descriptive ontology was still controlled by the abstract principle of E (instein)-observability, Heisenberg started out with.

The most important interpretative contribution of this paper is its attempt to explain what is to be understood by the new non-classical quantum mechanical kinematical variables of *place*, *velocity*, *trajectory*, etc. As in the relativistic paradigm, there is a syntactic aspect (of the mathematical model) which escapes sensible intuition and a semantical aspect which reinterprets the variables as constituting an appropriate set of observables. This involves condition Hv of the relativistic model, so far unexploited by Heisenberg. He included reference to an observer (interpreted here as including the measuring instrument) as part of the

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[1] AHQP, Heisenberg-Kuhn, 27 February 1963.

re-interpreted definition of the variable, and in so far, an epistemological part of the variable as described, as in the case of relativistic space-time. For instance, in his discussion of *place*, Heisenberg writes: "The concept of place necessarily involves reference to a way of measuring position relative to a frame of reference: otherwise the term has no sense."[2]

In the relativistic re-interpretation, the reference was a purely logical one, not taking into account the possible effects of a physical interaction between the object and the observer, an interaction that might possibly affect both. Heisenberg makes clear that in the case of quantum mechanics such an interaction is presumed and enters substantially into what quantum mechanics is all about. A variable is, by definition, an intelligible function of the appropriate measuring process. But, he points out, individual measurements are discrete processes which bind instrument and object through a shared and indivisible photon. In the case of position measurements, these discrete indivisible processes represent no more than a series of discrete locations spaced in time which do not constitute a continuous trajectory. If neighboring locations are joined by straight line segments, neighboring segments have discontinuous slopes on a position-time graph. The discontinuity in slope then measures the velocity (and momentum) uncertainty of the particle.

The new "place" variable is understood as the old intuitively grounded "objectifiable" variable but re-interpreted so as to make it relative to an instrument within the process of a measurement. He then makes the surprising claim: "All the concepts that are used in the classical theory for the description of a mechanical system can also be defined exactly for atomic processes."[3] It is clear from the context, however, that what Heisenberg intends to say is that the classical and quantum mechanical concepts have the same "operational definitions," in other words: the same measuring devices and procedures that are effective in measuring one are also effective in measuring the other. Measurement devices and procedures in the "operational" sense are described in the pre-theoretical language L_P and do not employ the implicitly defined relationships of the theory which would be taken to define a variable in the strict sense of the term. The same pre-theoretically described measurement procedures, he says, can be used to measure classical position and quantum mechanical position.

There is a quantum mechanical limitation, moreover, to the simultaneous observation of canonically conjugate quantities, such as position and momentum: "the experiments which lead to such definitions carry with them an uncertainty

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[2] Heisenberg (1927c) *op. cit.*, 174.

[3] Ibid., 179.

if they involve the simultaneous determination of two canonically conjugate quantities."[4]

Finally, since a quantum mechanical variable is an intelligible function of a measuring process, it is not clear whether the new position variable has observable instances apart from instances that are actually observed—an ambiguity due to Heisenberg's practice of using "observing" and "measuring" as synonymous terms.

Heisenberg tries to explain the simultaneous uncertainty in position and momentum by examples. It is not clear whether the purpose of these examples is to explore the nature of quantum mechanical systems or to provide examples of paradigmatic thinking in quantum mechanics. The latter seems to be the predominant consideration.

The first example concerns an electron of which all that is known is that it would be found on measurement somewhere in the interval $(q, q + dq)$. Heisenberg represents such an electron by a probability amplitude (or wave) $S(q)$, which, by the Born-Pauli statistical rules of interpretation, gives the probability distribution

$$|S(q)|^2\, dq$$

for finding the electron in the position interval $(q, q+dq)$. Heisenberg calls the standard deviation of the distribution Δq, the "position uncertainty of the electron." The probability amplitude $S(q)$ can be converted into the probability amplitude $T(p)$ for the momentum p by the appropriate quantum mechanical transformation rule. $T(p)$ yields the probability distribution

$$|T(p)|^2\, dp$$

for finding the momentum in the interval $(p, p + dp)$. Heisenberg calls the standard deviation of the distribution Δp, the "momentum uncertainty of the electron." Choosing a probability amplitude so as to give a Gaussian wave packet for q (and consequently for p), Heisenberg proves that

$$\Delta q.\ \Delta p > h/2\text{л} \tag{1}$$

This relation he interprets as the "direct intuitive content" of the commutation relation

$$pq - qp = h/2\text{л}i$$

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[4] Ibid.

The mathematical symbols p and q are the matrices (or in Dirac's theory q-numbers) which, according to the rules for "quantizing" a physical problem, replace the classical variables p and q, in the quantum mechanical description.

Δq and Δp, however, are statistical parameters for an ensemble of identically prepared particles and to the extent that intuitive classical notions are called upon, there is no logical reason, as Margenau, Jammer, and others have pointed out, why the commutation relation (1) should impose a limitation on the simultaneous measurability of q and p for an individual particle.[5] The statistical argument just given does not support the conclusion that simultaneous measurability of q and p in individual cases is subject to an Uncertainty Relation. For Heisenberg, however, the Uncertainty Relations state a restriction on the simultaneous measurability of q and p for an individual atomic system. Since this conclusion cannot be derived from the example, it is reasonable to suppose that Heisenberg introduced the example for the purposes of the paradigm alone.

The proof of the Uncertainty Relations for individual cases requires the use of more abstract principles. The proof (only implicit in these papers) follows from an application of the principle of E-observability to the transformation theory outlined in the *Drei Männer Arbeit*.[6] There it is shown that non-commuting matrices cannot be simultaneously diagonalized. Now diagonalizing a matrix displays the set of states in which the physical quantity takes a definite value in a realizable physical environment—that is, it represents the spectrum of observable values of the physical quantity and names the corresponding states of the system. The mathematical fact that non-commuting matrices cannot be simultaneously diagonalized, implies that there is no situation of object-plus-physical environment in which a definite value of one physical quantity co-exists with a definite value of a non-commuting quantity ("non-commuting" referring to the representative matrix operations). Basic to this inference, is the principle of observability that

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[5] H. Margenau, "Measurements and Quantum States," *Philos. Sci.*, **30** (1963): 1–16, 138–57; M. Jammer, CDQP, 330; P. Feyerabend, "Problems of Microphysics," in *Frontiers of Science and Philosophy*, ed. by R. G. Colodny (London: Allen and Unwin, 1964), 206, 208–17. K. Popper, *The Logic of Scientific Discovery* (London: Hutchinson, 1959), chap. ix. Note that if q and p are not simultaneously measurable, then q and p are not derived from one ensemble of data, but from two ensembles—one from which Δq is derived, and the other from which Δp is derived.

[6] A reminder here of E. Husserl's critique of modern science in *The Crisis of European Philosophy and Transcendental Phenomenology,* trans. by D. Carr (Evanston: Northwestern University Press, 1970); due to the loss of philosophical meaning, nature is reduced to a mathematical model.

restricts what can be observed and what, consequently, belongs to the real order within the legitimate interpretation of the mathematical model.[7]

How the Uncertainty Relations affect individual phenomena is dealt with intuitively in a series of examples. For example, Heisenberg considers the limitations imposed by the quantum of action on the ability of an X-ray microscope to localize a particle.[8] The example is worked out in a perfectly classical framework, the atomic system being treated as a classical point particle which interacts during the measurement process with a photon. The example satisfies the need for an intuitive explanation of how and why, within the classical framework, the classical quantities of position and momentum cannot be simultaneously measured. Whether the descriptive variables of the atomic system have (or should be taken to have) a specific quantum theoretic and non-classical meaning is not part of these considerations.

In another example, he treats the diffraction of an electron from a grating.[9] He visualizes the electron as a wave packet occupying a certain volume wider than the spacing of the grating. The spread-out wave packet reflects ignorance of the whereabouts of the electron. More accurate knowledge of the localization of the electron results in a smaller wave packet and less diffraction. Here the paradigm exposition seems to suppose that ignorance of where the electron is positioned within an interval $(q + \Delta q)$ implies a wave function of width Δq and moreover, that diffraction will occur if Δq is larger than the spacing of the diffraction grating.

I now turn to the criticism of this argument. In the first place, while it is true *for a quantum system* that a wave packet of width Δq implies relative ignorance of its position (this implies knowledge merely of the fact that it falls within the interval $(q, q + \Delta q)$), the converse does not follow. Secondly, ignorance of the precise position of a particle within the interval $(q, q + \Delta q)$ does not imply it has a wave function, for it could be a classical particle which is not subject to diffraction.

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[7] For a consideration of the role of models in physics, see E. McMullin "What do Physical Models tell Us?" in *Logic; Methodology and Philosophy of Science III,* ed. by B. van Rootselaar and J. F. Staal (Amsterdam: North-Holland, 1968), 385–96, as well as the references given there to Achinstein, Black, Hesse, and Suppes.

[8] Bohr pointed out that in Heisenberg's treatment of the X-ray microscope, there was a serious oversight—he had not taken into account the diameter of the microscope objective lens. Cf. AHQP, Heisenberg-Kuhn, 25 February 1963. Also Jammer CDQM, *op. cit,* 329.

[9] Heisenberg distinguishes between the *Schrödinger wave function,* which is a function in 3n-dimensional abstract space (for a system of n particles) and the *wave-packet* in what was soon to be called the "complementary wave picture." The latter was the de Broglie wave-packet visualized in the paradigm as a wave-packet in 3-dimensional classical space, but nevertheless not objectified as an element of the real world.

The argument from ignorance, then, presupposes a great deal that is not explicitly stated: it presupposes that the atomic system is a quantum theoretic object and, therefore, that it possesses a wave function and that its wave function has a known width Δq centered on the expectation value of q. The latter point is an inference derived from the quantum mechanical equation of motion and from the known objective conditions under which the system was prepared. From these, the theoretical solution can be found and an a priori estimate derived of what can be known. A priori limitations on what can be known (an objective uncertainty) need not correspond, however, with the a posteriori limitations on what is actually known (a subjective uncertainty). What Heisenberg meant to affirm is an objective uncertainty, that **is,** a limitation on what can be known. This uncertainty provides an upper limit to what is actually known in any case. It is a theoretical limit that underlies all practical and subjective limits and prepares the ground for a re-definition of the meaning of the term "position," in which the theoretical limit is incorporated in a new meaning as a constitutive element of that meaning. In the new meaning, a continuous trajectory cannot even be defined, since for a continuous trajectory, position and momentum must simultaneously have precise values at every moment. What Heisenberg's Uncertainty Principle shows is that, in the new meaning of the kinematical terms, quantum mechanical systems do not follow continuous trajectories, for the notion of trajectory is not definable in L_Q.

In the course of the paper, the two main themes are reiterated: that the new variables are relative to a measuring environment, and that the relation is based upon a measurement interaction with the environment.[10]

Bohr was critical of the paper in which the Uncertainty Principle was announced. He did not believe that new kinematical concepts were required for quantum physics, and in the course of the following months, he succeeded in bringing Heisenberg around to his view.

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[10] See Jammer's discussion in CDQM, sect. 7.1.

CHAPTER SEVEN

The Philosophical Differences Between Heisenberg and Bohr

The terms "reality," "descriptive concept," and "observability" had different meanings at this time for Bohr than they had for Heisenberg, indicative of deep philosophical differences.[1] Bohr was of the type of a Faraday grounded in imaginatively intuitive common sense. Heisenberg was more of the type of a Maxwell or an Einstein, exploiting mathematical structures that were imaginatively unintuitive [*unanschaulich*] to common sense in order to uncover new and hitherto unsuspected structures in nature. Bohr and Heisenberg were by basic temperament, and at this time explicitly, moved by incompatible philosophical values.[2]

For Heisenberg, at the start of his career in 1925, the mathematical formalism entered essentially into the definition of a physical concept. A physical concept for him was defined by implicit definition through the interpretation of those

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[1] The role of metaphysics as a heuristic for science is stressed by M. Wartofsky, and others. See, for example, his "Metaphysics as a Heuristic for Science" in *Boston Studies in the Philosophy of Science*, III (New York: Humanities Press, 1968) (eds.) R. S. Cohen and M. Wartofsky, 123–72. The most powerful philosophical critique of the reduction of natural science to mathematical models is E. Husserl's *Crisis of European Philosophy and Transcendental Phenomenology, op. cit*.

[2] Interesting in this connection are Heisenberg's reflections contained in an interview on 25 February 1963, AHQP, Heisenberg-Kuhn; also his published recollections "*Erinnerungen …*" TPTC, *op. cit*.

mathematical relations which the theory established between its own primitive terms. The domain of the physically observable, and consequently of the physically and descriptively real was then outlined by and through the interpretation of a mathematical theory. Here Heisenberg was reflecting his interest in Hilbert's axiomatization of geometry.[3] The notion of implicit definition was also used by Einstein and Weyl in their treatment of the kinematical concepts of relativity mechanics and the notion must have been well-known at Göttingen when Heisenberg was there. Following Einstein, Heisenberg held that implicit definition played the determining role in specifying what could or could not be observed and described, and hence what was or was not real.

Besides implicit definition, there is another element necessary to define the usage of a physical concept, this is the *ostensive* or *operational description* in the pre-theoretical language L_P of the situations in which the *theoretical primitives* of the physical system occur in an identifiable way. Consider for example, the case of *force*. Force is exemplified in a stretched spring, of which a description in pre-theoretical language L_P is, viz., "A stretched spring exemplifies force (as sensed by muscular effort)." Force, however, is also a theoretically defined quantity in L_N linked by Newton's Laws of dynamics and to Hooke's Law for a stretched spring. This latter role uses measure numbers in its description, viz., "The Newtonian force in the stretched spring is 10 kgs."

At this point, convention may—and in fact does—step in, clearly and decisively. It is an empirical fact of our culture that regularly and for the most part, the term "force" has come to mean (in non-relativistic cases) whatever obeys Newton's Laws for force. This is the linguistic norm prescribed by convention in our culture. It is based upon the assumption that Newton's Laws have sufficient empirical warrant. It is neither given immediately by experience, nor is it an a priori condition of experience or language—except to the extent that in conventional contexts we are bound by the conventions of our time and situation. Conventions, however, are decisions between possible alternatives; at another time for another community, the term "force" could mean, for example, that which is exemplified in the stretching of a spring whether or not Newton's Laws were fulfilled.

So the question arises: what is the relation between linguistic conventions and descriptive ontology? Does a description which is correct by conventional linguistic standards also stand correct by the standards required to provide an ontological description of nature? There are many who would hold that this is so and that the philosophy of nature is nothing more than a systematization of what is implicit

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[3] D. Hilbert, *Grundlagen der Geometrie* (Leipzig: Teubner, 1899), translated under the title *The Foundations of Geometry* (Chicago: Open Court, 1902).

in the linguistic conventions of particular communities at particular times. The philosophy of nature then becomes part of the history of ideas and the sociology of knowledge.

The reduction of the philosophy of nature to a socio-empirical discipline is, however, contrary to the Western philosophical tradition which has always considered them to be distinct. This tradition seeks to be normative for all places, times, and cultures; it deals not just with what is said to be the case but with how this should be described and lived to express the universal philosophical values of that tradition. These values are grounded in the belief that human life and experience have a common meaning and a common goal that is universal for the human species and that is rational, practical, and transcendental to individuals, societies, histories, and cultures. The philosophical tradition in the West began with the Greek philosophers of the sixth century B. C. E. To what extent did the young Heisenberg share these values?

Heisenberg loved the Greek classics and the classical music of Bach, Beethoven, and Schubert. He recounts that in the Spring of 1919 during the brief "Soviet" take-over of Bavaria and while he was serving briefly in the opposing Cavalry Rifle Division No. 10, he spent his off-duty hours on a rooftop reading the dialogues of Plato and while on duty around the lake of Starnberg he enjoyed discussing the nature of atoms.[4] In 1922–23, he went to the University of Göttingen to write his doctoral dissertation. Here the memory and philosophy of Edmund Husserl was strong throughout the departments of mathematics and natural science. He later became a friend and frequent visitor of Martin Heidegger, Husserl's student and Husserl's successor at the University of Freiburg-im-Breisgau. He wrote an essay for Heidegger's *Festschrift* on the significance of the quantum Uncertainty Principle.[5] Though most deeply attracted to Greek philosophy, and especially to the philosophy of Plato, he would have been familiar with the cultural critique of the materialism of modern science by Heidegger and Husserl.[6]

The roots of this critique, of course, go back to Heraclitus in the 6th century BCE who "mocked" the images and statues of the gods, but "reverenced" the gods

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[4] Cf, W. Heisenberg, *Der Teil und das Ganze* (1969), trans. as *Physics and Beyond* (1971).

[5] W. Heisenberg, "*Grundlegende Voraussetzungen in der Physik der Elementarteilchen*," in *Martin Heidegger zum siebzigsten Geburtstag: Festschrift* (Pfullingen: Neske, 1959), 291–297.

[6] E. Husserl's *Die Krisis der europäischen Wissenschaften und transzendentale Phänomenologie* was posthumously published in 1954; in this late work Husserl criticized the "teleology of Western culture" as having replaced reverence for "Being" with the search for "rational scientific explanation" as if this were the *Gesamt- und Grundwissenschaft* ("total and basic science"); such also was Heidegger's critique. Neither, however, deplored modern science; they deplored just its cultural misuse.

they represented, for, as he said, the gods were their "soul." To take a "rational scientific stance" towards nature is to make (mathematical) images of nature and to risk the denial of nature's "soul"—the human meanings that inhabit those very human images. Yet, what has characterized Western culture is the search for the illusory goal of *Gesamt- und Grundwissenschaft,* that is, of *total and basic science*. It could be said of both Husserl and Heidegger—and also eventually of Heisenberg—that, though mathematically trained, each came to recognize the illusory nature of this goal and in their own way came to "mock" the mathematical images and scientific representations of nature in order to show "reverence" for nature's "soul."

Certain features about the two thousand years of search for perfect scientific knowledge in the West are relevant to our present consideration because of the shock generated in the scientific community by relativity—special and general—and the quantum theory. In the first place, at the start of this trajectory, two roads were distinguished: Parmenides spoke of the Way of Opinion and of the Way of Reason. The Way of Opinion[7] followed the intuition of the senses, risking the danger of being carried along by the never-ceasing flow of sense experience into a world without constancies and invariances. The Way of Reason,[8] however, judged not by what seemed to be, but by the stable unchanging (generally mathematical) aspect of things which only Reason attained. This carried with it the danger of denying reality to secondary qualities and to real change in the natural world. The Way of Opinion was followed by Aristotle, Aquinas, Hume and the empiricist tradition. Among its representatives would be counted scientists of the Baconian inductive tradition, Darwin for example, Faraday and, to a large extent, Bohr. The Way of Reason[9] was followed by the Pythagoreans, Plato, Archimedes, Descartes,

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[7] Among contemporary authors, T. S. Kuhn and Agassi, for example, come close to identifying the philosophy of science with the sociology of knowledge. M. Wartofsky articulates a position which the present author finds more agreeable, in "Metaphysics as a Heuristic for Science" in *Boston Studies in the Philosophy of Science,* vol. III, *op. cit*. It is a position consecrated by the studies of P. Duhem, A. Koyré, A. Crombie, and others.

[8] Wartofsky writes: "The representation of the structure of science is a model (an interpretation, a mapping) of a more general and abstract theory of structure, which I take a metaphysical system to be … Then the history of alternative metaphysical systems reveals itself as a rich heritage of *theories of structure* in which the essential features of theoretical construction are set forth in the most general way": in his "Metaphysics as a Heuristic for Science" in *Boston Studies*, vol. III, *op. cit.*, 152.

[9] For studies of the influence that the Aristotelian and Platonic traditions had in the development of modern science, consult the classic work of P. Duhem, *Etudes sur Leonardo da Vinci* (Paris: Hermann, 1906–13), and various essays in the collections, *Towards Modern Science,* vol. I, ed. by R. M. Palter (New York: Noonday Press, 1961), *Scientific Change*,

and the rationalist tradition. Among its representatives would be counted scientists in the Archimedean or Platonic tradition, such as Galileo, Newton, Maxwell, Einstein, to which Heisenberg was drawn.[10]

In the second place, it became gradually clear that the ideal of perfect scientific knowledge could not be fulfilled in its original sense.[11] Looking back over the course of Western philosophy and science—and for most of its period philosophy was Western culture's attempt to reach perfect science—one sees that the first condition for perfect scientific knowledge, the necessity of a universal object, was the harmony exhibited by the universe. This led to the question: What binds all things together into an ordered, moving totality in which things come and go, in which men are born and men die, and in which the cycle of the seasons keeps pace with the yearly procession of the planets along the highway of the celestial zodiac? Whatever this is, it is the unifying element of the cosmos. For Aristotle it was the kind of teleological causality that accounted for the universal fact of motion. For Newton, it took the form of mathematical laws that governed the patterns of motion in a *containing* Euclidean space. Up to the time of Kant, it was possible to speak in objectivist language of unifying principles unrelated to the human spectators of the cosmic drama. With Kant,[12] however, the view of the human subject as a spectator of nature was supplanted by the view that in some sense the human subject constitutes the universal forms under which nature presents itself. The Kantian view attacks the scientific ideal, it denies that perfect science is capable of revealing nature independently of human presence and activity in nature. From the time of Kant on, science had to be open to the possibility that natural science depended on an active subject/object relationship and took the form of

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ed. by A. C. Crombie (New York: 1963). For the Aristotelian or empiricist influence, see, for example, J. H. Randall, Jn. *The School of Padua* (Padova: 1961), A. C. Crombie, *Robert Grosseteste and the Origins Of Experimental Science, 1100–1700* (Oxford: Oxford Univ. Press, 1953); L. Geymonat, *Galileo Galilei* (New York: McGraw-Hill, 1965), E. McMullin, "Empiricism and the Scientific Revolution," in *Art, Science and History in the Renaissance*, ed. by C. Singleton (Baltimore: The Johns Hopkins Press, 1968), 331–69.

[10] There have been many studies on the Platonic *influence* in the development of modern science. Besides the works listed in the note above, see, for example, E. A. Burtt, *The Metaphysical Foundations of Modern Physical Science* (London: Routledge and Kegan Paul, rev. ed. 1931), A. Koyré, *Etudes galiléennes* (Paris: Hermann, 1939), A. Meier, *Die Vorläufer Galileis im vierzehnten Jahrhundert* (Rome: 1949), A. Crombie, *From Augustine to Galileo* (Cambridge, Mass.: Harvard Univ. Press, 1953).

[11] P. A. Heelan, "The Search for Perfect Science in the West," *Thought*, 43 (1968), 165–86.

[12] Cf. I. Kant, *Critique of Pure Reason*, B xiii (p. 20 in N. Kemp Smith's translation).

an interrogative dialogue between human interrogators and nature's responses to human questioning.[13]

It has then to be taken as evident that humans themselves are one of the sources that contribute to the outcomes of dialogues with nature. But how do we define what this contribution from human sources is, and where it comes from? One source, of course, is the experimental practices and protocols by which humans interrogate nature in the protected environment of the laboratory. But how does nature respond? Heraclitus said that nature loves to hide! Does nature from its side interrogate humans? Is measurement a two-way interrogation? If not, then science would be a human monologue! If so, then science ought to be a rational collaboration with nature rather than what has often been described as a way to "subjugate" nature as if nature were an enemy or a reluctant native tribe. Collaboration would replace objectivity, and scientists would see themselves more as custodians and gardeners of nature than as conquerors of reluctant native tribes.

From the time of Kant on, it began to appear that the notion of a perfectly objectifiable cosmological science was a chimera. The human subject was recognized to be the active interrogator in a dialogue between humans and nature. Humans for their part only ask questions relevant to human interests; nature answers intelligibly only when its interests are involved. Human questions are translated into research methods capable of eliciting meaningful responses from nature. Such an active orientation of a searching and inquiring human subject toward a responsive horizon of nature is what is called by Husserl an "intentionality structure." It is the embodied mental engagement that gives an intelligible unity to a linguistic framework. A linguistic framework is the externalization of a common intentionality-structure in a community of common discourse.

Bohr and Heisenberg exemplified at this time two different models of rational thinking, each well represented in the Western tradition.[14] Heisenberg, on the one hand, represented the Archimedean-Platonic tradition.[15] Bohr represented a pragmatic "common sense" combination of the Kantian tradition and the empiricist-inductivist tradition; for him communication with colleagues would not be well served by insisting on a definitive philosophical discourse; instead he championed everyday—ordinary—language, L_O. Heisenberg disagreed; he believed that

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[13] P. A. Heelan, "Scientific Objectivity and Framework Transpositions," *Philosophical Studie*s (Dublin), 19 (1970): 55–70.

[14] For more thorough treatment of the differences between Bohr and Heisenberg, see P. A. Heelan, *Quantum Mechanics and Objectivity, op. cit.*, and P. K. Feyerabend "The Recent Critique of Complementarity, I and II," *Philos. of Science*, 35 (1968): 309–31and 36 (1969): 82–105.

[15] AHQP, Heisenberg-Kuhn, 11 February 1963; CDQP, 176–9.

the ontology of nature would not be well served unless the physical terms were taken to be defined implicitly by the mathematics of the physical theory. In this he agreed with Einstein's position on relativity physics. He advocated therefore a new descriptive kinematical and dynamical language for quantum physics that would reflect its new mathematical formalism. For him this new language would replace both L_N and L_P, because for him the ontology of nature would not be well served by these modes of discourse, although he agreed that there was a useful and, perhaps, even necessary place for them, in designating the domain of appearances to which quantum mechanical concepts applied.

Heisenberg did not at first question the possibility that science would discover in due time descriptive—even measurable—concepts of a non-classical kind. Such a descriptive concept would be exemplified in quantum data, the outcome of quantum measuring processes. A quantum datum event would be signified by the occurrence of a classically describable signal (e.g., a pointer reading, photographic record, etc.), but the description of the quantum datum entity made present by the measurement would not be made in classical terms but in a future non-classical L_Q. The non-classical kinematical and dynamical properties would be defined by implicit definition within the hermeneutical circle of a non-classical kinematical and dynamical theory. *In the abstract sense of "observability" with which Heisenberg started, that is, in the sense we have called "E-observability," these non-classical quantities would be observable and endorsed as part of the descriptive ontology of nature in non-classical* L_Q.

Bohr, however, belonged to a different rational tradition. He was given more to *intuitive reasoning*, and working with a *paradigm* to get a *feel* for the physics of the case, and using mathematical formulations only as convenient tools to express imperfectly the content of his intuition. Physical reality for him was not circumscribed by an interpreted mathematical theory: it was revealed in a vague intuitively grasped way wherever and whenever people communicated with one another, even before the concepts were put into mathematical form. Influenced by the thought of William James, he took words to be mysteriously evocative of a great deal more than could be mathematized.[16] For Bohr, everyday language L_O was the sole bearer of descriptive ontology. The language of classical physics, L_N, was for him an idealization of L_O. L_O was an important instrument to refine, generalize, objectify, and to bring under predictive control large areas of the rich but vague domain of what everyday language described. But whatever ontological status L_N enjoyed, it borrowed it from L_O.

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[16] Mario Bunge would call this "direct observability," *Scientific Research II, op. cit.*, 162.

A consequence of his basic philosophical standpoint was a more restrictive use of the terms, such as "reality," "descriptive concept," and "observation." I have already noted that *reality* for Bohr was *the objective content of what ordinary language L_O described or of its refinement in classical physical language L_N*. Descriptive concepts for Bohr were to be found solely in L_O or L_N. That there might be descriptive concepts yet to be discovered which were not of a classical character was ruled out by his philosophy. Finally, "to observe" meant for him "to register an event describable in the descriptive predicates of L_O or L_N and localized in a space-time neighborhood." Let us call the sense of *observability* derived from the latter meaning, "B-observability." The Principle of B-observability would then sanction as "real" only those states of affairs that were localizable and describable in ordinary language or in the descriptive language of classical physics.

Heisenberg relates that he and Bohr during the early part of 1927 disagreed over the proper use and interpretation of the two forms of the quantum theory—matrix mechanics and wave mechanics.[17] Schrödinger had persuaded Bohr during a meeting at Copenhagen that wave mechanics was at least as useful as matrix mechanics for dealing with quantum phenomena and Bohr became convinced that an adequate quantum theory had to include both in one system. By February 1927 he believed he had the solution to the paradigm problem, and also to the philosophical problem, in the new concept *complementarity*. It was not necessary, he thought, to invoke allegedly new kinematical concepts: it was sufficient to learn to restrict suitably the domains of applicability of the old concepts. This involved a new kind of logic, based on an epistemology of *mutually exclusive (i.e., 'complementary') ways of using descriptive statements* in a language; he called this usage "complementarity." He opposed Heisenberg's view then that new descriptive kinematical/dynamical concepts were required. Whatever can be described, can be described, he held, in everyday language L_O or in L_N. What was needed was a new way of using predicates that were complementary; it introduced into logic (really, epistemology) conditions under which a particular classical concept could be used and when it could not be used. Complementarity, then, was a strategy to preserve the old language but to use it systematically in a new way. By Spring 1927, Bohr had succeeded in persuading Heisenberg that complementarity was the correct solution.[18] "What was born in Copenhagen in 1927," Heisenberg wrote some years later, "was not only an unambiguous prescription for the interpretation

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[17] Heisenberg, "*Erinnerungen* …" TPTC, *op. cit.*; also AHQP, Heisenberg-Kuhn, 11 and 25 February 1963.

[18] AHQP, Heisenberg-Kuhn, 25 February 1963.

of experiment but also a language in which one spoke about Nature on the atomic scale and, insofar, a part a philosophy."[19]

In spite of the opposition of some notable physicists, among whom were Einstein and Planck, complementarity, or the Copenhagen interpretation as it was also called, very quickly established itself in the scientific community. The Fifth Solvay Conference in the autumn of 1927 was the occasion for a major confrontation between Bohr and the antagonists of complementarity, especially Einstein. While Einstein was not then or ever convinced that complementarity was the correct path for quantum physics to take, he admitted he could not find a flaw in Bohr's logic. Heisenberg recounts that by the end of 1927, it began to be said everywhere that those people in Copenhagen seemed by all accounts to have an impregnable position and from that time on, he says, the burden of proof lay with those who disagreed with them.[20]

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[19] W. Heisenberg, "The Development of the Interpretation of the Quantum Theory" in NBDP, 15.

[20] AHQP, Heisenberg-Kuhn, 28 February 1963.

CHAPTER EIGHT

Complementarity

Bohr's view on the quantum theory has been well discussed and analyzed by a number of writers, among them Petersen, Meyer-Abich, Feyerabend, Bunge, Heelan and others.[1]

Bohr's first major address on complementarity, given at Como in September 1927, covered the same ground as Heisenberg's paper on the Uncertainty Relations.[2] It was both an essay in the philosophy of nature and an attempt to propose a quantum theoretic paradigm. The two main elements of Bohr's 1927 Como

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[1] A. Petersen, *Quantum Physics and the Philosophical Tradition* (Cambridge, Mass.: M. I. T. Press, 1968); K. Meyer-Abich, *Korrespondenz Individualität Komplementarität* (Wiesbaden: Franz Steiner Verlag, 1965); P. Feyerabend, "Complementarity," *Proc. Aristot. Soc.*, Suppl. **32** (1958), 75–104; "Problems in Microphysics" in *Frontiers of Science and Philosophy*, ed. by R. G. Colodny and C. G. Hempel (Pittsburgh: Univ. of Pittsburgh Press, 1963); "On a Recent Critique of Complementarity I and II," *Philos. Sci.*, **35** (1968): 309–31 and **36** (1969): 82–105; M. Bunge, "Strife About Complementarity I & II," *Brit. Jour. Phil. Sci.* **6** (1955): 1–12 and 141–54 See also Jammer's discussion in CDQM, sect. 7.2.

[2] The occasion of Heisenberg's address was an international congress on the centenary of Volta's death. The text entitled, "The Quantum Postulate and the Recent Development of Atomic Theory" was published in the collection, ATDN, 52–91.

lecture are (i) the wholeness of the quantum phenomenon, and (ii) the closure of quantum phenomena.[3]

(i) *The wholeness of the quantum phenomenon is the indivisibility of observer and observed.* This indivisibility has a *physical sense* (denying the existence of a precise physical boundary between the observer and the observed), and a *logical and epistemological sense* (denying that an observed predicate has a definite meaning unless related to an observer). Physical indivisibility results from the union of object and instrument through indivisible quanta of energy in the measuring-process.

The physical indivisibility of observer and observed leads to the mutually exclusive (i.e., complementary) character of two kinds of descriptions (a) *localized space-time coordinatization* that supposes the system is being 'observed' and described in classical particle language; and (b) *causality* or the law-like development of the isolated system in time under the laws of conservation of momentum and energy when the system is not being 'observed.'[4] Because of the de Broglie-Einstein relation between energy-momentum and wave length, wave-picture language can be used of such a system, the two cases, 'being observed' and 'not being observed,' being no more than idealized extremes.

Bohr's usage of the term "observed" here is subtly different from Heisenberg's. For Heisenberg, *to observe* is *to describe the effects of a measurement*. For Bohr, *to observe* is *to describe the effects of a localization*. Thus he speaks of the "*complementarity of observation and definition*": where "*observation*" means *localization* and "*definition*" means *isolation from influences that might localize the system and render its momentum or energy indeterminate.*

(ii) The *closure of the quantum phenomenon* occurs *when the terminal event which is the outcome of a quantum mechanical measuring process is described*. What takes place between the 'closure of the phenomenon' and 'its description' cannot be described. The term "describe" here is used with its customary ontological connotation of "that's the way things are." Petersen gives the following summary: "*Complementarity* came to refer exclusively to the logical relationship between quantum phenomena that involve the same kind of object but are brought about by different types of instruments."[5]

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[3] Petersen, *op. cit.*, 123–27.

[4] Some authors, e.g., C. F. von Weizsäcker, interpreted Bohr to mean that complementarity related the space-time (observational) description to the (causal) ψ-function description. Bohr rejected this interpretation, stating that the complementary description to the space-time (observational) description was the description in which energy and momentum were preserved. Cf. C. F. von Weizsäcker, *Vom Weltbild der Physik* (Stuttgart: Hirzel, 8th ed. 1960), 330. See also Jammer CDQM, *op. cit.*, 356.

[5] A. Petersen, *op. cit.*, 127.

Two comments need to be made. Firstly, Bohr never worked out in formal fashion the logic (and epistemology) of complementary descriptions. There have been many attempts to do so, and we shall return to them later on. Secondly, Bohr held that the descriptive linguistic framework, L_N, of classical physics was both necessary and sufficient to describe all quantum phenomena. In this, he differed from the position taken by Heisenberg up to and including his paper on the Uncertainty Relations, that is, until Heisenberg was persuaded to give up his earlier position in favor of Bohr's.

Bohr's philosophy was intuitively bound up with his reflections on language. We are immersed in language, he would say. Language was not only the vehicle of human communication, its norms of usage constituted a set of objective meanings which limited what could be meant or stated in words. Language was a priori to every description. Either a descriptive concept was already in the language, or it could be paraphrased or used figuratively in the language. If in a particular case none of these was true, the particular case was incommunicable, and if incommunicable, it did not belong to the most public of all realms, that of what we call 'reality.'

For Bohr, the language which was a priori to all description was ordinary language L_O, the language which scientist and non-scientist shared, and which constituted a meeting-place for the largest public. Its vagueness was indicative not of poverty but riches: it was the home of all being and reality, that is, of all that is. Science grew by refining, generalizing, idealizing the rich content of which all human beings are already in some way in possession. Certain consequences follow from this view. Firstly, only that can be conceived which can be communicated, and therefore only that can be represented by language. Secondly, reality is that domain of objects most publicly accessible. This implies a rejection of the principle of E-observability which makes abstract mathematical structure the norm of the real, since abstract mathematical structure is not publicly accessible to all. Thirdly, only those intuitive mathematical structures in physics which are idealizations or refinements of what is described in ordinary language can represent the ontology of the real. Preeminently among those are classical physics and its descriptive framework L_N.

L_N has a special relation to ordinary language since it is the descriptive framework of those "idealizations of the real" which are expressed by classical Newtonian-Maxwellian physics. The concepts of classical physics, called "classical concepts" have an altogether special place in Bohr's philosophy, since they have the highest degree of objectivity and are the medium of the most precise and unambiguous communication within the widest public. So perfect is the objectivity of classical physical concepts that their truth seems to be timeless and independent of particular cultural communities. They give an intuitive apodictic representation of the world-for-human beings as given in ordinary experience. Bohr's conception of the role of L_N was undoubtedly influenced by Kant. This did not appear in the Como lecture of 1927 but became evident, for example, in the paper he contributed to the jubilee volume dedicated to Max Planck in 1929,[6] in which he attributed the limitations of conception and language to the "forms of perception" under which we necessarily apprehend what we do apprehend. He summarizes his philosophy: "All new experience makes its appearance within the frame of our customary points of view and forms of perception."[7]

Beyond ordinary experience lie other domains to be known, and among them is the domain of quantum systems. Quantum systems, however, transcend the realm of what can be described by the descriptive language of classical physics. This is Bohr's "quantum postulate," which attributes to any atomic process, "an essential discontinuity or rather individuality completely foreign to the classical theories."[8] Moreover, the Kantian element in Bohr's philosophy led him to take the position that it was not in our power to construct non-classical descriptive concepts to cover the quantum domain. This inability to conceive and describe atomic processes does not prevent us, however, from predicting and describing the (classically describable) effects of their interaction with a (classically describable) measuring environment. "Complementarity" teaches one "to play between the two pictures, particles and waves," "observation" and "definition," "localization" and "causality." Such "playing between the two pictures, particles and waves" constituted Bohr's paradigm for quantum physics.

For Bohr, the inability to conceive a non-classical descriptive framework was also profoundly connected with problems of communication and language. Whatever one means and intends by one's words, they have an objective meaning for the community at large which is independent of one's will and intention. There is a sense established and entrenched in the community: its 'common sense' judges the correct usage of words. Either one conforms to that usage, or one is judged to be, willfully or not, incorrect in your use of language. In addition, Bohr attributes Kantian a priori status to "common sense" and its idealization in classical physics (L_N), with the consequence that revolutions in the conceptual frameworks of physics are in principle ruled out.

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[6] N. Bohr, "The Quantum of Action and the Description of Nature" in ATDN, *op. cit.*, 192–101.

[7] Bohr, ATDN, *op. cit.*, 1.

[8] *Ibid.*, 53.

Bohr's basic philosophy was then strictly incompatible with Heisenberg's, for Heisenberg believed in the creative power of an individual scientist, such as Einstein, to get the community to change its 'common sense.' Up to March 1927, Heisenberg believed he was in possession of a new non-classical descriptive framework and that he was leading a scientific revolution. It was Bohr who persuaded him that there was no need of a new framework, that the scientific revolution could be accomplished by giving new roles with restricted domains of applicability to old classical concepts. The sense of this transposition is sufficiently obscure to call for a more thorough analysis to which I will return below.

In spite of the fact that the fundamental philosophies of Bohr and Heisenberg seemed to be mutually incompatible, they eventually came to endorse the same paradigm, one which is attributed correctly to Bohr.

CHAPTER NINE

The Chicago Lectures 1929: Complementarity Adopted

In 1929 Heisenberg delivered a series of lectures in Chicago.[1] In the Preface to their publication, he wrote that his aim was to make known the *Kopenhagener Geist der Quantentheorie,* central to which was "the complete equivalence of the corpuscular and wave concepts." In the lectures he refers to Bohr's conclusive studies of 1927. Heisenberg set out to show that every quantum theoretic problem could be worked either with particle concepts in the "particle picture" or with wave concepts in the "wave picture."[2] Such "pictures," he wrote, belong to the "imaginable" or "visualizable" but represent, however, microscopic objects that are too small to be imagined or visualized by a human sensibility tuned by evolution to macroscopic bodies. Heisenberg says these imaginary "pictures" of the microscopic are "analogues" of what microscopic bodies are. I take him to mean, that these microscopic bodies are represented in L_N (or L_R), the space-time of macroscopic bodies, but

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[1] W. Heisenberg, *The Physical Principle's of the Quantum Theory*, trans. by C. Eckart and F. C. Hoyt (Chicago: Chicago University Press, 1930); refs. are to the Dover edition. It is referenced as PPQT.

[2] PPQT, preface. Heisenberg used the term "pictures" for the particle and wave frames of reference.

are too small for humans to imagine or experience.[3] Of the wave and particle "pictures," Heisenberg continues:

> "It is a trite saying, that 'analogies cannot be pushed too far,' yet they may be justifiably used to describe things for which our language has no words … for [our language] was invented to describe the experience of daily life … words can only describe things of which we can form *mental pictures* and the ability to do so is *learned in daily experience*. Fortunately, mathematics is not subject to this limitation and it has been possible to invent a mathematical scheme—the quantum theory—which seems entirely adequate for the treatment of atomic processes; for *visualizing*, however, we must content ourselves with *two incomplete analogies—the wave picture and the corpuscular picture*."[4] [Emphasis added]

The role of *observability* in connection with measurement is again emphasized, and it has not lost for him its ontological role in relation to the mathematical space-time(s) of the theory. What does Heisenberg mean by the analogical "visualizing" of a microscopic entity? Does he mean that the entity is revealed within the ontology of L_N (or L_R)? Or has one to go one step further: to 'read' the measurement event (in L_N or L_R) as a 'word'—a communication about some frame beyond L_N or L_R say, a non-classical quantum space-time frame, L_Q, in which the ontology of the quantum system is embedded? I will return to this topic later. In the Chicago Lectures, however, Heisenberg clearly did not go beyond the use of L_N (and L_R).

The more abstract sense of "observability," which I called E-observability, is less evident here because it relates to only one part—the role of the mathematical framework of the analysis. However, "observability" has another side, namely, "localizability" in the space-time of observation and measurement. Heisenberg and Bohr agreed that what is "pictured," whether by "analogy" (Heisenberg) or by limiting modes of predication (Bohr), is also "observable" and describable as a localized event in the space-time of classical physics. Classical space-time is then the space in which quantum events make their presence known and in relation to which they are described; in this sense it is both the *representational space of quantum mechanics and the space of its ontology*. The strategy of "complementarity" then

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[3] Interviewed a long time later, Heisenberg stated that Bohr was critical of the central theme, believing it was premature to assert that every problem could be worked in either "picture." Bohr himself took the position that the "pictures" in some cases had to be used jointly—for example, a particle could be "visualized" as a very small wave-packet. What the Chicago lectures *claim* is no more than the systematic use of the resources of these two "pictures." AHQP, Heisenberg-Kuhn, 25 February 1963.

[4] Heisenberg, PPQT, *op. cit.*, 10–11.

is to set limits to the domains of applicability of classical or relativistic concepts which are assumed just to 'idealize' the pragmatic living space of human beings.[5]

This 'complementarity' approach raises many logical/epistemological questions. If, following Hilbert's theory of implicit definition, all the concepts of L_N are interrelated in one indivisible hermeneutic circle, then it *follows* that these conditions hold only when the system displays its presence in isolation from the conditions that produce quantum complementarity. How then are the two mutually exclusive descriptive languages used?

Bohr and Heisenberg seem to have agreed that the ontology of the quantum system is tied to prudential ways of managing the linguistic resources of L_N (or L_R) because of the principle of E-observability that connects the mathematical framework of quantum mechanics to the ontology of quantum systems. Heisenberg, however, never relinquished his belief in the principle of implicit definition which he took to be the modern counterpart of the Platonic geometric forms of the *Timaeus*.[6] He proposed that human knowledge grows by the construction of "*abgeschlossene Theorien*" or "Closed Theories;"[7] a Closed Theory is an axiomatic system, such as Newtonian Mechanics, with a more or less well-defined domain of valid applicability in experience. The essential core is the mathematical interrelatedness of the terms. Its domain of applicability is limited and its boundaries, described in ordinary language, are forever open to revision. The terms of a Closed Theory lose their referential meaning outside of the theory's proper domain.

Heisenberg concludes that the indeterminacy of quantum events is due to the fact that what we can know about them is an inextricable mixture of parts, some contributed by the activity of the subject and others by the activity of the object. We recall that the traditional requirement for scientific thinking is a sharp division between the observing subject and the observed-and-described object. The division is in the domains of logic and epistemology, as well as in the domain of ontology and actuality. Determinacy in the domain of classical physics may seem possible

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[5] For a discussion of the relationships between classical and quantum mechanics in various limiting cases that involve our two *correspondence conditions* (Hi) and (Hii), see E. L. Hill, "Classical Mechanics as a Limiting Form of Quantum Mechanics" in *Mind, Matter and Method*, ed. by P. K. Feyerabend and G. Maxwell, *op. cit.*, 430–48.

[6] For example, Heisenberg, PPNS, 11–26, 60–70, 117; "*Kausalgesetz and Quantenmechanik*," *Erkenntnis*, 11 (1931): 172–82; "*Der Begriff 'abgeschlossene Theorie' in der modernen Naturwissenschaft*," *Dialectica* II (1948): 331–36; PCN, 27–28; PP, 93, 98–101, 172–75, 181–82, 200; "Planck's discovery and the philosophical problems of atomic physics" in *On Modern Physics* by W. Heisenberg et al., (NY: Collier Books, 1962), 9–28; cf. also AHQP, Heisenberg-Kuhn, 27 February, 1963.

[7] This idea is often repeated in Heisenberg's later writings, e.g., PPNS, 30–36, 57; 67–75.

only because the mutual dependencies of subject and object are negligible in the macroscopic order. In the atomic domain, however, the mutual dependencies can cause relatively “uncontrollable and large changes in the system observed.”[8] The union between the observer and the observed in the atomic domain is such that it seems to be impossible to define the interface unambiguously.[9] Since the domain of description seems to be just the space-time of the observer which is either L_N or $L_{R,}$[10] actual knowledge of complementary pairs is limited to irreducible statistical distributions and correlations (in L_N or L_R).

Heisenberg also considered the consequences for *causality* of the lack of a sharp division between subject and object in quantum mechanics. Of the historical family of notions to which the term “causality” applies,[11] he chooses to consider

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[8] PPQT, 3, 20–46, 64.

[9] *Ibid.*, 5, 8, 64, 67.

[10] *Ibid.*, 2–54.

[11] The literature that is directly relative to the meaning of *causality* generally is rather extensive; the list of works given below includes some of the most important readings and is not intended to be exhaustive: Plato, *Greater Hippias* 296e, *Cratylus* 413a, *Phaedo* 103b, *Philebus* 26e, *Timaeus* 29b-d and 43a–47e, and *Laws* 894c–895b; Aristotle, *Categories* 12.14^{b}10–22; *Posterior Analytics* i.2. 71^{b}33–72^{a}6, and ii, 94^{a}20–95^{a}35; *Physics* 11. 6. 198^{a}5–13 and iii. 2–3.202^{a}2–202^{b}–22; *Metaphysics* i. 1.981^{a}25–30 and 981^{b}5–30. See also *Metaphysics* i. 2. 982^{a}25–30, and 982^{b}5–10; ii.1–2. 993^{b}23–994^{b}30; iii. 2. 996^{a}18–997^{a}14; v. 2. 1013^{b}3–16 and 1014^{a}20–25; vi. 2. 1026^{b}24–1027^{a}15; viii. 3. 1043b5–14; x. 1. 1052^{b}8–14; xi. 8. 1065^{b}2–4; xii. 4. 1070^{b}22–35; Newton, *Mathematical Principles of Natural Philosophy*, Bk. III, Rule i–11; *Optics*, Query 31. See also Third Letter to Bentley, in *Isaac Newton’s ‘Papers and Letters on Natural Philosophy*, ed. by I. B. Cohen (Cambridge, Mass.: Harvard University Press, 1958), 300–309. P-S. Marquis de Laplace, *A Philosophical Essay on Probabilities,* trans. by F. W. Truschott and F. L. Emory (New York; Dover: 1951), 4; Hume, *An Enquiry Concerning Human Understanding,* sect. 3, par. 18, sect. 5, pt. 2, part. 28–33, sect. 8, par. 75. See also *A Treatise of Human Nature,* Is pt. 3, sect. 2, 7, and 14. J. S. Mill, *A System of Logic,* Bk. III, chap. iii, sect. 1; chap. v, sect. 7 and 8. Kant, *Critique of Pure Reason, passim*; E. Mach, *Science and Mechanics*, trans. by T. J. McCormack (La Salle, Ill.: Open Court, 1919), 579; A. Einstein, “*Physik und Realität*,” *Journal of the Franklin Institute*, 221 (1936), 313; E. Cassirer, *Determinism and Indeterminism in Modern Physics*, trans. by O. T. Benfey (New Haven: Yale University Press, 1956), 58–88. See also *Substance and Function*, trans. by W. C. Swabey (New York; Dover: 1953), 226–27, n. 85; P. W. Bridgman, *Reflections of a Physicist* (New York: Philosophical Library, 1955), 207–209. M. Born, *Natural Philosophy of Cause and Chance* (Oxford: Clarendon, 1949), 108. In the same work see also Einstein’s Letters (1944 and 1947), 122; D. Bohm, *Causality and Chance in Modern Physics* (London: Routledge and Kegan Paul, 1958), 1–15; and *passim.* M. Bunge, *Causality* (Cambridge, Mass.: Harvard University Press, 1959), 1–53 and *passim*; see also *The Myth of Simplicity* (Englewood Cliffs N. J.: Prentice-Hall, 1963), 180–203; E. Nagel, “The Causal Character of Modern

just one, namely, *causality* as *a law-like sequence of localizable events*—"Natural phenomena obey exact laws." This, he says,[12] is vacuous because in quantum mechanics, law-like connections among the states exist only when the system is isolated, and isolated systems are not natural observable phenomena. Atomic states, insofar as they are phenomena, i.e., observed localized objects, do not obey the traditional Principle of Causality, since observation re-distributes the energy and momentum of the conjoined system of observer and observed object with a consequent loss in exactitude and predictability. The disturbance is due to the sharing of ultimate and indivisible quantities of energy between the observer and observed object.

With respect to the act of measurement and observation, the influence of the measuring device brings about a discontinuous change in the system. The influence of the measuring device "is treated in a different manner from the interactions of the various parts of the system,"[13] since, unlike the measuring environment, the parts of the system enter into the description deterministically—they contribute to the system's wave function that develops predictably under the system's Schrödinger Equation. The wave function of the system, at any moment, can be represented as a superposition of eigen states; there are usually many ways of doing this because there are usually many different sets of commuting observables. An act of measurement of a particular observable will leave the system in one of the eigen states of that observable, chosen at random by the process of measurement. Measurement produces a discontinuous change in the pure state of the system; this is called "the reduction of the wave packet."[14] The measurement will affect the susceptibility of the system to future possible interactions with observables that do not commute the one measured. When the description of the system is changed by measurement from a wave-picture (characteristic of an isolated system) to a particle-picture (characteristic of an observed, i.e., localized system), the correlations among the wave-picture which compose the superposition state of the wave function are suppressed. Consequently, the order of measurements will determine what kind of publicly objective path the system takes over time.

It is worthwhile to dwell for a moment on the "reduction of the wave packet," one of the strangest and most controversial aspects of quantum mechanics. In the

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Physical Theory," in *Readings in the Philosophy of Science,* ed. by H. Feigl and M. Brodbeck, Pt. V, 419–37; See also E. Nagel, *The Structure of Science* (New York: Harcourt, Brace and World, 1961), 316–24; A. Pap, *An Introduction to the Philosophy of Science* (New York: The Free Press of Glencoe, 1962), 251–317; N. R. Hanson, *Patterns of Discovery* (Cambridge University Press, 1961), 50–69; *Symposium on Causality*, *Synthese,* 18 (1968): 1–108.

[12] PPQT, 62–63.

[13] *Ibid.*, 58.

[14] *Ibid.*, 36, 39.

Chicago lectures, Heisenberg works out some cases. For example, he considers a single photon striking a semi-transparent mirror.[15] After interacting with the mirror, it possesses a "pure case" wave function Ψ that is composed of a reflected term Ψ_R and a transmitted term Ψ_T; these are superposed waves that are mutually orthogonal to one another[16], i.e.

$$\Psi = \alpha\Psi_R + \beta\,\Psi_T \tag{1}$$

where

$$|\,\Psi\,|^2 = |\,\Psi_R\,|^2 + |\,\Psi_T\,|^2 = 1 \tag{2}$$

and

$$|\alpha|^2 + |\beta|^2 = 1 \tag{3}$$

Equations (2) and (3) say that in many measurements of identically prepared photons, the photons will be found on the reflected side of the mirror 100 $|\alpha|^2$ per cent of the time and on the transmitted side 100 $|\beta|^2$ per cent of the time.

It naturally occurs to someone not yet introduced to quantum mechanics to suppose that the photon after interacting with the mirror is definitely on one side or other of the mirror, though we do not know on which side.[17] The situation would seem to be similar to one where darts are thrown in the dark at a black target on a black wall. Some darts will fall inside the target, others will fall outside, but we do not know which have gone where until the room is lit and the "hits" and "misses" have been inspected and counted. Measurement in such a situation merely means removing ignorance about events that have already transpired. If this is the presumption regarding the photons and the semi-transparent mirror, one would be moved to represent the current state of the photons during the experiment as a virtual ensemble of "hits" and "misses." Such an ensemble is called a "mixture."

A "pure wave-function," however, is not simply a "mixture"; in some respects it is like a mixture but in other respects it is very different.[18] *Subsequently to actual*

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[15] This and similar examples are considered by Heisenberg in PPQT, 39, 55–62 and elsewhere.

[16] PPQT, 56. For the difference between pure and mixed states, see J. L. Park, "Quantum Theoretical Concept of Measurement: Part I," in *Philos. Sci.*, 35 (1968): 205–31.

[17] Cf. PPQT, 59–62.

[18] PPQT, *passim*, 2–54. This statement was proved for the more formalized Hilbert space axiomatization of quantum mechanics by J. von Neumann in *The Mathematical Foundations of Quantum Mechanics*, trans. by R. Beyer (Princeton: Princeton University Press, 1955).

measurement, both yield the same proportions of reflected and transmitted photons and they have identical expectation values for any variable that commutes with the reflection-transmission operator. However, *antecedently to measurement* when the photons are represented by a "pure wave-function," there are a number of important differences, such as the following:

(i) expectation values generated for a pure case wave function Ψ differ from those of a mixture in certain cases, for example, when the observable operator does not commute with the reflection-transmission operator.
(ii) Even though, a pure case and a mixture give identical outcome *subsequent to measurement,* under the Copenhagen Interpretation the anticipated outcome *antecedent to the decision to measure* is different, since in this case the wave function Ψ refers to an individual system, say, A, while *subsequent to the decision to measure,* Ψ refers to a virtual ensemble of systems like A.
(iii) Returning to the semi-transparent mirror experiment: if the photon is not absorbed in the measurement process, its representation changes abruptly on measurement from Ψ to Ψ_R (for a reflected photon) or Ψ_T (for a transmitted photon). The new representation can be used for predictive purposes, but not for *retrodictive* purposes. This is called the *Projection Postulate*.[19] A second measurement immediately following the first should then confirm the outcome of the first measurement with 100% probability. In the case of a mixture, however, the representation changes with time, but the new representation can be used for *retrodictive as well as predictive* purposes. Of course, if the photon is absorbed in the measuring process, the new representation can be used *only for retrodictive purposes*.

The *reduction of the wave packet,*[20] mentioned above, expresses the central core of the Bohr-Pauli statistical interpretation of quantum mechanics. It states that the outcome of an act of measurement converts the antecedent pure case,

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The theorem proved that in a pure case there are no dispersion-free ensembles other than those in which only one basic state is represented. His conclusion from this is that as long as one accepts the present form and interpretation of quantum mechanics, there is no set of hidden variables capable of defining a set of basic microstates relative to which set an arbitrary pure case could be shown to be a dispersion-free mixture.

[19] The name "projection postulate" was given by J. von Neumann, *Mathematical Foundations etc., op. cit.* Cf. also PPQT, 66–76.

[20] Cf. PPQT, 36, 39 and *passim*.

e.g., $\alpha\ \Psi_R + \beta\ \Psi_T$, into a subsequent mixture in which Ψ_R and Ψ_T appear with relative probabilities $|\alpha|^2$ and $|\beta|^2$ respectively.

The Copenhagen Interpretation, however, leaves an important question unresolved: To what extent is the reduction of the wave packet a real natural phenomenon? And to what extent is it just a linguistic (or logical) question, a way of thinking and talking about the quantum measurement process? If the wave function Ψ describes a quantum mechanical system as it is (rather than just a useful way of thinking and talking about it), then it would be reasonable to ask, at what point in the measurement process does the "reduction of the wave packet" take place, that is, at what point are the phase relationships which characterize the pure case destroyed? Does the reduction take place irrespective of whether or how a human observer-describer thinks and talks about it? Or is it just a matter of whether or how a human observer-describer thinks and talks about it? And if the latter, how can thinking and talking—or language or logic—account for the differences already noted between the physical predictions based upon the difference between a pure case and the corresponding mixture?

Discussing the example of a photon impinging on a semi-transparent mirror, Heisenberg notes that the original wave packet divides into two parts, a reflected part (Ψ_R) and a transmitted part (Ψ_T) that are in a pure state of superposition. If now an experiment—a measurement—is made in a position occupied by the reflected packet, this "exerts a kind of action (reduction of the wave packet) at the distant part occupied by the transmitted packet, and one sees that this action is propagated with a velocity greater than that of light."[21] Heisenberg adds, "however, it is also obvious that this kind of action can never be utilized for the transmission of signals so that it is not in conflict with the postulates of the theory of relativity."

At first sight, the above argument seems to constitute a claim that the reduction of the wave packet is a real phenomenon brought about by real influences transmitted through space with a speed faster than light. Taking into account, however, the distinction between *paradigm* (concerned with useful ways of thinking and talking about events) and *description* (concerned with the descriptive ontology of events) and recalling that the purpose was to propose quantum mechanics in and through the wave-particle paradigm, the sentences just quoted take on a different value, one which no longer enables us to answer the basic question that was posed.

The elements of a coherent solution were, however, already a part of Heisenberg's thought. He supposes that descriptive concepts relate a system through a measurement interaction to a relevant environment (such as an equipped laboratory) in which the system is observed. Consequently, different descriptive concepts relate a system

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[21] PPQT, 39.

to different environmental contexts of measurement. Quantum mechanics, however, says that some pairs of measuring processes cannot be simultaneously realized, such as precise position-measurement and precise momentum-measurement. The transposition of linguistic framework, say, from position-language to momentum-language, implies as a truth-condition a change in the environmental context of the quantum measurement process; the system cannot have precise position and momentum relationships in the same environment; a choice has to be made between two different and incompatible environments. A pure case, then, is an incomplete description of the system, a specific laboratory environment has to be imagined and used without which the descriptive concepts of a pure case are vacuous.[22] A mixture, on the other hand, supposes that a different descriptive goal has been chosen, and that consequently—with logical necessity—a different context of measurement has to be imagined and used without which there is no real expectation of a virtual ensemble. Thus, a transposition of measurement context involves a corresponding transposition of linguistic framework—and vice versa, a transposition of linguistic framework implies a change in the physical environment with which the system interacts. An actual description of the system in terms of one set of predicates (its state description) may then involve physical changes in the system that would not have occurred had another set of predicates been used for the state-description.

The paper on the Uncertainty Relations and the Chicago lectures take important positions relative to the theory of quantum mechanical measurement. Since the quantum mechanical variable is a dimension of the measuring interaction between object and instrument, two questions naturally arise: Can this interaction itself be described? And is it logically necessary for the performance of a measurement that the measurement interaction and its outcome be described? As a physical process, the measurement interaction is, of course, subject to description by physical science, just like any other physical process, say, the scattering of electrons by a nucleus. But a measuring process is not just a physical process, it is a physical process used as a medium for information transfer to an observing scientist and the public scientific community. It is then an information-theoretic process as well as a physical process, and vice versa.

Can such a process proceed without a prior critical awareness on the part of the observing scientist that the outcome of the physical process is essentially an information channel destined to inform the scientific public? Or is this critical awareness a logically and epistemologically necessary part of the performance of the measuring process? In the former case, the act of observation is non-inferential;

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[22] Vacuous, though not incomplete relative to what Margenau calls the “preparation of state” of the system, H. Margenau, *Philos. Sci.* 4 (1937): 352–56; **25** (1958).

in the latter case, it is inferential, proceeding from a prior description of the physical process of interaction and its outcome to a conclusion about the description of the quantum mechanical object. I shall return to the discussion of this point in chapter xi. In the meantime, let me enumerate some of the positions taken by Heisenberg, which have been incorporated into the "orthodox" theory of quantum mechanical measurement.[23]

In the first instance, he expresses the view that the object-cum-macroscopic instrument, treated as one complex physical system has its own wave function and Schrödinger equation.[24] Heisenberg said merely that the physical interaction between the object and the instrument *could* and *should* be treated quantum mechanically. Later authors, however, stated the interaction should be so treated, if a correct solution is to be obtained.

Secondly, the description of the physics of a measuring process is also implied here, although not explicitly elaborated.[25] A measuring instrument for quantity Z is a piece of apparatus that fulfils certain conditions: that the eigen states of the combined system object-cum-instrument are all of the form:

$$\Phi(z_i)\Psi_i$$

Where z_i is the i-th position of the relevant dial or indicator on the instrument, and $\Phi(z_i)$ the eigen state of the instrument corresponding to this position of the indicator; Ψ_i is the i-th eigen state of the measured object. In this case, a reading z_i of the instrumental indicator is uniquely correlated with an eigen state Ψ_i of the measured object. If the measured object is initially in a linear superposition state, say,

$$\lambda_1 \Psi_1 + \lambda_2 \Psi_2 + \lambda_3 \Psi_3 + \ldots.. \lambda_n \Psi_n$$

then the outcome of the measurement interaction considered as a quantum mechanical process governed by its Schrödinger equation will be a pure case superposition of the form:

$$\lambda_1 \Phi(z_1)\Psi_1 + \lambda_2 \Phi(z_2)\Psi_2 + \lambda_3 \Phi(z_3) \Psi_3 + \ldots.. \lambda_n \Phi(z_n)\Psi_n$$

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[23] By the "orthodox" theory of quantum mechanical measurement, I mean the account given by J. von Neumann, *Mathematical Foundations*, *op. cit.*, chap. vi; G. London and E. Bauer, *La théorie de l'observation en mécanique quantique; Actualités scientifiques et industrielles*, No. 775 (Paris: Hermann, 1939); E. Wigner, "The Problem of Measurement," *Amer. Jour. Phys.*, **32** (1966), 208–11; M. Yanase, "Optimal Measuring Apparatus," *Phys. Rev.*, **123** (1961), 666–68; and a vast literature, much of a very speculative nature. See CDQM, sect. 9.2.

[24] PPQT, 58, 66–67.

[25] *Ibid.*

Such a physical state cannot be the observed outcome of a measurement of Z, since the only values Z can have are z_1, z_2, etc. The wave function must first be reduced to a mixture. This reduction corresponds to the reduction of the compound system to a virtual ensemble of systems with definite eigen values. The latter reduction is effected by an observation of the compound object-cum-instrument system.

Thirdly, for Heisenberg, it is sufficient for the reduction of a pure state wave function that the quantum mechanical observer interact physically with the object to be observed within a suitable laboratory measurement environment, and that a macroscopic informational signal occur within the measurement environment that can be described in classical terms but is "read' for what it communicates about the quantum system. The reduction of the wave packet is due to the indeterminate physical effect of the macroscopic observer-cum-instrument on the system. In the case that what is observed is the compound instrument-cum-object, the quantum mechanical observer is the person of the scientist who experiences the sensory flux from the instrument-cum-object and has been trained to "read" it appropriately as containing information about the quantum object.[26]

Finally, immediately after the measurement, the instrument is in an objective state $\Phi(z_i)$ (which can be verified publically by a host of scientific colleagues) and the object is correlatively in state Ψ_i. A second measurement of the object a short while later by the same or by another instrument will show that the object is in state Ψ_i or in a state very close to Ψ_i. This claim was later called "the Projection Postulate."[27]

That the partially indeterminate effects of the macroscopic observer on the system are responsible for the reduction of the wave packet is a view not shared by the exponents of the "orthodox" theory of quantum mechanical measurement. This supposes that it is due to the occurrence of a psychic act of "introspection" or "auto-observation," as London and Bauer[28] call it, alluding to a theory of "psycho-physical parallelism" that was later picked up by John von Neumann and Eugene Wigner. Psycho-physical parallelism is one of several attempts to "explain"

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[26] *Ibid.,* 36, 39, *passim.*

[27] For an excellent and critical account of the "orthodox" theory of measurement and the Projection Postulate, see H. Margenau and J. L. Park, "Objectivity in Quantum Mechanics" in *Delaware Seminar in the Foundations of Physics*, ed. by M. Bunge (New York: Springer-Verlag, 1967), 161–187.

[28] According to London and Bauer, human sensibility has the "characteristic familiar power which we can call 'power of introspection'" by which it can take cognizance to its own state and so emerge from the indeterminacy of a mixture to the determinacy of fact by an act of auto-observation, *op. cit.*, 42. This "power of introspection" leads on in the direction of the phenomenology of E. Husserl, M. Heidegger, and M. Merleau-Ponty.

the relation between human consciousness and neurophysiology. There is no doubt that photons falling on the retina produce neurological effects in the brain that are necessary conditions for human consciousness of the world, that includes perception, memory, and language use. Our environment makes us aware of our selves, others, and the natural and cultural world in which we live in communities. There is clearly a two-way embodied channel of meaningful communication between people and their local environment. How does this work? Philosophy, psychology, physiology and other sciences try to make sense of how brute material forms of sounds and gestures in space and time, become "meaningful" to people—in many more dimensions than those of space and time. How are meanings created, passed on, reviewed periodically, and changed historically? It is this process of meaning-making that came to be the focus of studies by psychologists, such as G. Fechner, philosophers, such as I. Kant, E. Husserl, M. Heidegger, theologians, such as Augustine of Hippo, Thomas Aquinas, F. Schleiermacher, B. Lonergan, and also in the present century, anthropologists, linguists, cognitive scientists, and many others. How does meaning move back and forth across the Body/Mind interface? Is there such an interface? If there is none, how is meaning generated through the embodiments that conscious mental activity uses and seemingly needs to use?

A theory of psycho-physical parallelism was originally introduced by Gustav T. Fechner in psychology and was applied to physics by Wilhelm Ostwald in his *Lectures on Natural Philosophy.*[29] "Psycho-physical parallelism," he wrote, "starts from the premise that for each mental event there exists a corresponding physical event"—actually a neuro-physiological event. Classical parallelism claimed that mental events "mirrored" events in the world external to the human body. Psycho-physical parallelism claims only that mental events parallel the order and structure of neuro-physiological events, without however "mirroring" them. Ostwald was read by Heisenberg who seems to have been influenced somewhat by his thinking, but the explicit introduction of psycho-physical parallelism into quantum mechanics is due to Bohr[30] and John von Neumann. The latter used it in his classic account of measurement from which the so-called "orthodox" account

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[29] Gustav Fechner's work was used by Wilhelm Ostwald, *Vorlesungen in der Naturphilosophie* (Leipzig: Veit, 3rd ed. 1905), 398–99. The passage is found in translation among the excerpts added to PCN either by Heisenberg or his editor. The quotation is taken from p. 150 of PCN.

[30] N. Bohr, "The Atomic Theory and the Fundamental Principles Underlying the Description of Nature," (1929), ATDN, 92–119.

of the quantum mechanical measurement process is derived.[31] The "orthodox" account is that developed by von Neumann, London and Bauer, Wigner, Yanase and others.[32] In it, the object-plus-neurophysiological system is treated as a closed quantum mechanical system. The human knower comes to recognize the physical state of his own neurophysiological system by an act of "introspection,"[33] and then infers from that the state of that part of the closed system external to his own body, namely, the instrument and the object. This comprises the "orthodox" account of the reduction of the wave packet various aspects of which will be taken up in the next chapter.

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[31] J. von Neumann, *The Mathematical Foundations of Quantum Mechanics*, *op. cit.*, chap. vi, especially p. 420.

[32] See n. 23.

[33] This argument supposes the applicability of quantum mechanics to macroscopic objects as well as to microscopic objects. For a discussion of the possible role of consciousness in quantum mechanics, see E. Wigner, *Symmetries and Reflections* (Bloomington: Indiana Univ. Press, 1967), chap. xii, "The Problem of Measurement," and chap. xiii, "Remarks on the Mind-Body Problem"; also see A. Shimony, "Role of the Observer in Quantum Theory," *Am. Jour. Phys.,* **31** (1963): 755–73.

CHAPTER TEN

"Observation"

However, in the Chicago lectures, there are several disconcerting ambiguities in Heisenberg's use of terms related to "observation" (such as "observable," "observability," and so on). He attributes one sense to Bohr which I have called "B-observability," and he uses a different sense when he is expressing his own views, which I have called "E-observability." Bohr himself commented on the ambiguous meaning of the term "observable" in his Como lecture:

> "[Heisenberg's] Matrix theory has often been called a calculus with directly observable quantities. It must be remembered, however, that the procedure described is limited to just those problems, in which in applying the quantum postulate the space-time description may largely be disregarded and the question of observation in the proper sense therefore placed in the background."[1]

The reason for this reserve is that an electron in a stationary atomic energy level cannot be observed in Bohr's sense while remaining in that energy level. An object is "observed" in Bohr's sense if and only if it is observed at a localized space-time position.[2] But to localize an orbital electron would require a photon with energy at least as great as the binding energy of the electron, and sufficient therefore to

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[1] Bohr, ATDN, p. 72.

[2] To be localized means to occupy a definite space-time place to the exclusion of other places.

detach the electron from the atom. An orbital electron could thus be observed as part of an atom, but not more than once, since the fact of observation would result in the disintegration of the atom.

Heisenberg's original notion of observation, however, which I have called "E-observability" allowed that the electron is "observed" if an event occurs that is understood to be a transition of the electron from one energy level to another. The transition event manifests the existence of the two termini of the transition, termini which are in this sense "observable" even though the electron has not been localized as a space-time object. The broadly rationalistic meaning of "E-observability" evidently expands the ontology while the more empiricist meaning of "B-observability" contracts it.

Heisenberg eventually used the ambiguity in the meaning of "observability" to be transferred to the *Principle of Observability.* In his later thinking, two kinds of reality came to be associated, with the two kinds of observability. The reality of "actuality" ("*Aktualität*," "*Wirklichkeit*") was associated with B-observability. The weaker reality of "potentiality" ("*Potentialität*"), "standing in the middle between the idea of an event and the actual event," was associated with E-observability.[3] We will return to this point later.

Heisenberg himself draws attention to another kind of ambiguity, namely, the arbitrary way in which the distinction between subject/object or observer/observed is drawn.[4] The fundamental difference between a classical physical description and a quantum mechanical description is that only in the latter case has one expressly to take into account the observer's contribution to the production of the observed object and the constitution of the object's description.

The observed object is an achievement of human consciousness that depends on a chain of physical links connecting the atomic system to the human sensory cortex. This chain can be divided into two parts by a *cut* (or *partition; 'Schnitt'* in German) which from an epistemological point of view separates the observer-subject on one side of the *cut* from the observed object on the other side.[5] The observer and the observed are linked physically across the cut by indivisible quanta of energy. The location of the partition, however, is not determined by the physics of the situation; from this point of view, the physical location of the cut is indeterminate. The position of the cut is determined by the observer's epistemological

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[3] PP, 41.

[4] PPQT, 58–64.

[5] The mobility of the 'cut' became an important part of von Neumann's theory of measurement and of all subsequent writing on quantum mechanical measurement. Cf. J. von Neumann, *The Mathematical Foundations of Quantum Mechanics*, *op. cit*. Cf. also NBDP, 27.

choice; it is the prerogative of the scientist to decide where it falls to achieve the purpose of the observation and it can be moved at will. Thus, two different accounts can be given of an experiment by moving the cut from one position to another. The change in description does not involve a change in the experimental situation for nothing in the physical situation has been changed.

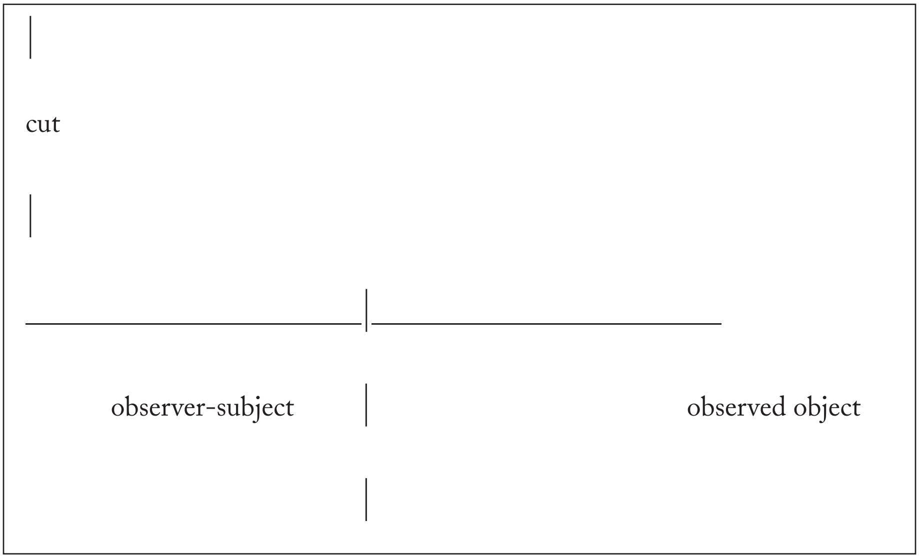

Figure 1. Schema of a measurement process marking the epistemological 'cut' between the observer-subject & the observed object.

Figure 1 is a general schema of a measurement process: the observer-subject is represented to the left of the cut and observed object is represented to the right of the cut. The cut partitions the measuring process into observer-subject and the observed object. The cut, however, can be located in either one of two positions. In position (1), the observer-subject is just the scientist; the apparatus is the observed object, such as the laboratory environment and the dial display; these are always classical objects. In position (2), the observer-subject is the scientist-cum-apparatus, and the observed object is the measured object, classical or QM.

To begin with position (2): this is the cut relevant to QM measurement, and to the gaining of QM data. In position (2) the QM observer is constituted by the human subject-cum-apparatus. Although Heisenberg sometimes speaks of instruments 'observing,'[6] he does not thereby claim that instruments 'observe' without

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[6] PP, 106, 137; NBDP, 22.

the participation of a human subject.[7] The role of the instrument in 'observation' is fulfilled only when it has been 'read' in L_Q and endorsed by a competent scientist[8] (standing in for the scientific community). A valid observation, then, does not require that all the links in the physical and cognitive chain be simultaneously activated. It is sufficient that the record be inspected, 'read,' and endorsed by a competent scientist.

In position (1), the true object is not a QM object, but the instrumental record of the measurement made, and the laboratory protocols of that measurement or of any potential object (classical or quantum); these objects are describable only in L_O or L_N (or possibly L_R).[9]

The language to be used in the description of the object measured will be determined by the position of the cut. If the apparatus is not on the observer's side of the cut, the object will be the state of the apparatus, as explained above. But since the object acquires its indeterminateness by interacting with the apparatus, the appropriate language for describing the QM object will be an appropriate QM language, L_Q, in which the indeterminateness of the observed QM object is expressed vis-à-vis the QM observer.

In the course of time, Heisenberg reflecting on the revolutionary nature of quantum mechanics centered his attention more and more on the role of the QM observer in quantum mechanics and the strange character of the observer/observed cut in the new physics.

Certain authors, such as J. von Neumann, G. London and E. Bauer, E. Wigner—authors of the (so-called) "orthodox" theory of QM measurement process[10]—have claimed that the coherence of physics implies that the subject/object cut can in principle be displaced indefinitely in the direction of the observer even to some point within the sensory neuro-physiological system of the human observer at which the cognitive activity of the human observer is engaged and fulfilled. This fulfillment—namely, the recognition of human consciousness—was seen as the product of a non-interactive act of "introspection" founded on

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[7] PP, 52; NBDP, 27–8.

[8] PPQT, 3, 58, 64, 66 and *passim.* Cf. also PP, 137 and Heisenberg, *Erkenntnis, op. cit.,* 183.

[9] Both Bohr and Heisenberg took L_N, the language of classical physics, to be no more than a refinement of L_O, ordinary language. For a criticism of this view, see below. Also see P. A. Heelan, *Quantum Mechanics and Objectivity* (The Hague: Nijhoff, 1965), chaps. iv and x.

[10] Most of the scientists just mentioned conjectured that the quantum theory was a universal physical theory applicable both to microscopic and macroscopic objects, to laboratory apparatus as well as to microscopic objects.

the principle of "psychophysical parallelism."[11] Heisenberg does not endorse the "orthodox" view.[12]

The role which the QM observer plays in the QM description of atomic nature needs further analysis. In the classical picture of the world, the furniture of the world consists of particles and fields. Particles are localized bodies, each momentarily to the exclusion of all other things occupying its own place in space, and each moving along its own continuous trajectory in Space and Time. This was part of what Heisenberg called "the ontology of materialism."[13] One characteristic of classical objectifiability is the claim that the existence and description of a material body is independent of its being observed by people or instruments. The cut between a (classical) observer and a (classical) object separates the two from one another logically, epistemologically, and physically; also the cut between them is not movable. The (classical) observer plays the role of an immaterial uninvolved spectator-describer of nature's dance; its descriptive predicates—those of L_N—do not include the observing subject logically or ontologically in their hermeneutical circle. Moreover, the activity of observation and description does not in principle require that the observer be physically linked with the object. Heisenberg writes:

> "Classical physics was built on the firm foundation of the recognition of the objective reality of events in time and space, which take place according to natural laws independently of mental activity. Mental processes appear to be only an image of this objective reality which is separated from the world of time-space relations by an unbridgeable gap[14]."

The conformity between the (classical) observer, Mind, and the (classical) object, Matter, was explained in various ways which are all forms of epistemological parallelism. For Spinoza, for example, mental and physical processes were dual aspects of one natural fact. For Leibniz, the two processes were dual but irreducible causal sequences, one mental and the other physical, developing simultaneously and in

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[11] For example, J. von Neumann writes, "That the boundary can be pushed arbitrarily deeply into the interior of the actual observer is the content of the principle of psycho-physical parallelism …, but this does not change the fact that in each method of description the boundary must be somewhere," *Mathematical Foundations*, *op. cit.*, p. 420. Cf. also, London and Bauer, *op. cit.*, and A. Shimony, *Amer. Jour. Phys.*, **31** (1963), 755–73.

[12] Heisenberg says "it is important that a large part of the universe, including ourselves, does *not* belong to the object," PP, 52. In *Quantum Mechanics and Objectivity, op. cit.*, p. 73, I mistakenly interpreted Heisenberg's remarks on p. 27 of NBDP as indicating an endorsement of the "orthodox" theory of measurement.

[13] PCN, 14; PPNS, 22, 81–82; NBDP, 28; PP, 129.

[14] PPNS, 92–93; also excerpted from Ostwald's *Lectures on Natural Philosophy* in PCN.

parallel by a pre-established harmony. In neither does the knower (here, the observer) contribute anything to the constitution of the known (here, the observed) object.

A classical object as described is in principle a closed system, that is, a system not in physical contact with a classical observer. One consequence of this position is that the measuring interaction is, at best, only incidental to classical physics, and, at worst, a nuisance because it interferes with the isolation of a closed classical system; it introduces perturbations and reduces the confidence-level of the measured values. A classical theory of measurement is then correctly called 'a theory of errors' since it is founded on the view that only the imperfection of the measuring process leaves us ignorant to some degree of a quantity's actual value. Classical physics then aims at describing systems in physical isolation from possible instrumental environments. It also supposes a theory of knowledge in which the observer 'mirrors' Matter without contributing anything to the constitution of the descriptive frame used.

Classical materialistic description is not repudiated by Heisenberg as simply false. He points out that it correctly describes much of the everyday world, but it does not correctly describe all that is in nature.[15] Having developed historically as a mode of biological and social adaptation to a macroscopic environment, it is not to be expected that its domain of validity extends beyond the macroscopic to the microscopic domain.[16] The limitations of its proper domain of applicability were revealed by quantum mechanics. Quantum mechanics, he says, "forced us to revise the fundamentals of science and has convinced us that there can be no such firm foundation of all perception,"[17] the firm foundation in question is the principle that Mind or consciousness produces an objectifiable image of reality through perception. However, psycho-physical parallelism was for Heisenberg, as also for Bohr, a necessary condition of possibility of a true-objective ontological description. For that reason, they limited the descriptive ontology of physics to what could be described in L_O or L_N.

A breakdown of parallelism would occur if a knower contributed either to the production of the object known, or to the description of this object. Taking the latter first, a knower contributes to the description of an object if a logical analysis of the descriptive frame would reveal the observer to be an implicit term in the hermeneutical circle of meanings intended by the description. This is the case in relativity, where space-time is defined as relative to a local inertial observer.

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[15] PPQT, 62; PPNS 23, 65, 86; PP, 44, 144.

[16] W. Heisenberg, "*Der Begriff 'abgeschlossene Theorie' in der modernen Naturwissenschaft*," *Dialectica*, II (1918) 331–36.

[17] PPNS, 92–93.

The observer might also contribute to the production of the object known by producing the venue (the laboratory) of its appearance and by interacting physically with the object in this venue. What is observed then, is an object in physical contact with the observer and as modified by that contact.

A QM account is such an account; it involves the observer in both a physical and logical interplay with the observed object. As Heisenberg put it: "Natural science does not simply describe and explain nature: it describes nature as exposed to our method of questioning."[18] And again:

> "Thus the aim of research then is no longer an understanding of atoms and their movements 'in themselves,' i.e., independently of the formulation of experimental problems. From the start we are involved in the argument between nature and man in which science plays only a part, so that the common division of the world into subject and object, inner world and outer world, body and soul is no longer adequate and leads us into difficulties. Thus, even in science, the object of research is "'no longer nature but man's investigation of nature.'"[19]

A quantum mechanical description, then, describes the object system as a function of its interaction with a QM observer. The object system is not as in classical physics a closed and isolated system. Moreover, the QM observer is not a separated immaterial Mind, but a knower-describer incarnated in an instrumental situation, that is, in human sensory organs and in external instrumentation. Being an embodied knower-describer, the QM observer is as much a part of nature as is the object observed; it too is subject to a physical description.

According to the theory of knowledge implicit in Heisenberg and Bohr, the QM observer can be described classically, from the descriptive standpoint of a classical Mind. From this it follows that the human sensory organs, the external instrumentation and any modifications of these can be described in objectifiable fashion in L_O and L_N. Such a description is given entirely in physical terms and contains no reference to the cognitive activities of the QM observer. What is so described is the physical neurological and instrumental complex in which the physical event takes place which is correlated with the mental event of knowing the QM object.[20]

However, a QM account can also be given of the external apparatus. This assumes the descriptive standpoint of a subject embodied in the sensory organs of a human observer and interacting quantum mechanically with the apparatus.

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[18] PP, 81.

[19] PCN, 24.

[20] See chap. xi for the distinction between *sign-fact* and *signified fact*, and chap. xv for the distinction between two forms of subject-object cuts.

The new descriptive standpoint puts the apparatus on the observed object-side of the cut; this is different from the old descriptive standpoint which put the apparatus on the observer-subject side of the cut.[21] The apparatus then becomes a QM object, and enters into the cognitive awareness of an observer (the person of the scientist) when the observer interacts with it and experiences what Bohr calls "a sensation."[22] A sensation is the cognitive awareness which a subject has of the physical event (neuro-physiological in this case) produced in the subject's brain by the QM object that is cognitively referred to the QM object. The QM object in this case is the external apparatus. The only descriptive predicates used, however, are those presumably belonging to L_O and L_N that are appropriate to the description of a neuro-physiological event in the describing subject. The QM account of the apparatus then is indirect. It does not describe what the instrument is like, but like the QM account of any QM object, it describes the kinds of effects it produces in a QM observer and relates these to the QM object as to (in some sense) their cause.

Certain consequences follow from this argument: (i) The universe of material phenomena in its totality would not have a QM account, since the QM observer-describer, from whose point of view the description is made would have no bodily vantage point from which to observe and describe this kind of object.[23] (ii) Every QM description made by a QM observer would leave some physical part of the universe undescribed; this physical part would contain a knower-describer.[24] (iii) In QM descriptive language L_Q, the descriptive predicates would belong to L_O and L_N and would be directly applicable only to qualified QM observers. In this case, whatever could be said of the QM object is said indirectly as related to events describable in L_O or L_N occurring in or to the QM observer; also; and in this case, L_Q would not have its own proper predicates but would borrow the predicates of L_O and L_N, use them in a special way.

Heisenberg's commentary on this situation is that the object of scientific research is "man's investigation of nature," and "nature exposed to our method of questioning."[25] "The quantum theory reminds us, as Bohr has put it, of the old wisdom that when searching for harmony in life one must never forget that in the drama of existence we are both players and spectators."[26] There is a profound

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[21] NBDP, 27.

[22] Bohr, ATDN, 1, 5, 8, 16f, 53. Cf. n. 1, chap. Xii.

[23] NBDP, 27.

[24] NBDP, 27–28; PP, 52.

[25] PCN, 24.

[26] PP, 58.

wisdom in those words not just for physics but for any attempt to comprehend the world we live in.

The critique above only concerns the dogmatic character of psycho-physical parallelism that would in principle rule out any science, such as QM, that supposes the Mind or the observer is embodied in an instrumental situation. The critique does not touch the Cartesian account of classical physics or everyday knowing.

CHAPTER ELEVEN

Observation and Description in Quantum Mechanics

The principal function of Mind, Spirit or Consciousness is to experience, observe, describe, and situate the new quantum entities in the reality of the world we live in. These are deeper and more fundamental constituents of physical reality than the objects of classical physics that explain the visible and tangible physical objects of the world of everyday human experience. Quantum mechanics raised problems about this deeper level of physical constitution.

Heisenberg in his Chicago lectures of 1929 was the first of the founders of quantum mechanics to make a detailed presentation of the new physics to a group of American physicists. In those lectures he set out to teach American physicists how to think, imagine, understand, and explain the kind of microscopic entities that are objects of the new quantum mechanics. Though too small and exotic to be picked up as individual entities by the unaided human sensibility, quantum entities had to be in principle "observable" as entities distinct from one another and from other kinds of scientific entities, as well as distinct from the scientific 'observer.' To be identified and studied as objects of natural scientific research, quantum entities had to be available to scientific 'observation' and 'description.'

Heisenberg took up this challenge at the beginning of his Chicago lectures. We will address the following four questions: (i) What does it mean for a scientific entity to be '*observable*' and '*describable*'? (ii) What special problems arise in claiming the '*observability*' and '*describability*' of quantum mechanical systems?

(iii) '*Observability*' and '*describability*' in the natural science require *two distinct linguistic frames*: the frame L_O (considered as standing in for the more precise L_N, or L_R; see iv below) appropriate for the description of the measurement process and the response of the measuring apparatus, and the frame L_Q appropriate for the description of the QM object about which the apparatus 'speaks.' How are these frames related to one another? (iv) What is the relation between the *everyday descriptive linguistic frame* L_O and the *descriptive frames* L_N and L_R?

(i) What does it mean for a scientific entity to be 'observable' and 'describable'?

In ordinary usage, for an observer *to observe* in L_O entails the following conditions[1]:*'To observe'* has as its object a definite descriptive sentential content 'that-p' where 'p' is (1) an assertion, (2) made by a particular observer (subject, describer, speaker) in an appropriate socio-historical community, (3) who describes the presence of a *fact* (*object*), that sits in a public descriptive *frame* (*context or horizon*), and (4) is represented by the vocabulary and grammatical resources of L_O, L_N or L_R (see below).

(i a). The description 'p' performs a 'realistic' function, that is, it asserts univocally (or at least analogously—see below) the real presence of an objective fact;

(i b). This real presence is appropriately represented in the sensory medium of the observer, and

(i c). It is represented publically within a public discursive descriptive frame that entails a priori a constellation of invariant contextual conditions, subjective/social ('intentional,' that is, intending 'reality in the social world') and objective (it has a horizon/niche in the social world); *the observer subject must possess the cultural (e.g., scientific, linguistic, and philosophical) background shared with the relevant community of descriptive discourse, and participate in the cultural and scientific activities that constitute the objective horizon of the discursive frame.*

(i d). Moreover, '*to observe that-p*' within the appropriate discursive frame entails a certain '*perceptual immediacy*' in the cognitive relation between knower and

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[1] For an excellent discussion of *observation* and *fact, cf.* N. R. Hanson's *Patterns of Discovery* (Cambridge: Cambridge Univ. Press, 1958), 4–49. Also cf. Bunge, *Scientific Research I*, *op. cit.*, 150 and *Scientific Research II*, *op. cit.*, 162–69 where there is an alternative analysis of *observation* and *observability*. The present author finds Bunge's analysis of the major epistemological themes difficult to comprehend and (possibly as a consequence) only partially convincing.

known, so that with expertise the mediating channel becomes transparent—'seeing becomes recognizing common worldly reality.'

We suppose, with Heisenberg,[2] the view that, when the expert QM observer 'observes' within the measurement process, the quantum mechanical usage of 'to observe that-p' does not differ from its usage in ordinary language. This claim needs a critical analysis.

(ii) What special problems arise in claiming the 'observability' and 'describability' of quantum mechanical systems?

(ii a) For Heisenberg, the process of measurement is a continuously connected process within which the QM observer-subject is bodily joined to, yet mentally distin-guished from, the QM observed-object; the epistemological dividing line between these two is called the 'subject/object cut' or just the 'cut.' Central to his analysis are two diverse 'ways of reading' the measuring process, one focused on the laboratory procedures and the other focused on the QM data received.

In the first 'reading,' the 'cut' is in position (1) between the scientist and the measuring instrument. What is perceived is twofold: the state of the equipment and the 'reading' of the media dials. In this reading, the scientist functions as the local manager of the laboratory environment within the descriptive (horizon) of L_O (or L_N or L_R).[3] This is the reading that epistemologically precedes the recognition of the presence of the QM object in the descriptive horizon of QM events. In the second reading, the 'cut' is between the measuring instrument and the QM object in its descriptive horizon.

In the second reading, the cut is in position (2), with the scientist joined physically and epistemologically to the measuring instrument. The observer is the instrumentally-enabled-scientist who recognizes the presence of the QM object in its descriptive horizon. In this function, the instrumentally-enabled-scientist works and discourses not in the context of L_O but in the context of L_Q. What is 'given' as a datum is the *actual presence of the* QM object *in the horizon of the laboratory*; in addition its 'measure number' is 'given.' What does the measure number

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[2] On p. 64 of PPQT, Heisenberg endorses the view that 'observation' takes its usage from ordinary language. This claim, however, has to be examined critically, and will be later.

[3] A 'context-language' is a language descriptive of the physical and epistemological conditions of possibility—namely, the context—for the valid use of an object-event descriptive language.

bring with it? Einstein suggested that it was no more than a tag, like the coat-check number of your overcoat—it tells you where in the cloakroom your overcoat is, but tells you nothing about the overcoat or whatever else is hanging on the numbered hook.[4] What seems to be lacking is any *essential intuitive* (*anschaulich*) *property it possesses as its own independently of its laboratory horizon.*

In this performance, the QM observer-subject is the scientist-embodied-epistemologically-in-the-measuring-instrument. The "cut" isolates the QM object as 'observable' and distinct from both the scientist and the measuring instrument, but not of its laboratory horizon. In this respect, the analogy with the special theory of relativity (STR) helps us to understand the local observer-subject's role.

The function of the local QM observer here is analogous to the function of the local inertial STR observer; it is to represent how the facts or events produced by an actual measurement process are 'contextualized.' Such local observers function in QM like local inertial STR observers; they are not unique but belong each to a relevant class of observers that have equal access to all measurable facts or events. In STR this class of local observers is specified by the notion of the "*Universal Inertial Observer.*" In quantum mechanics, this place is taken by the notion of the "*Universal QM Observer.*"[5] It is within this notion of a universal theoretical and practical worldly structure that local 'real' and 'actual' QM observables, namely, possible QM data in their appropriate QM horizons, are 'given' to human observers embodied in quantum measurement processes.

The two perceptual tasks—event recognition coupled with the appropriate horizon recognition—do not require any physical change in the laboratory, but are differentiated only by the scientist's choice: either to observe the instrumental environment—the QM horizon—objectively, or to 'read' what the medium 'discloses' objectively about the QM event/object that has occurred within this horizon. The measure number (datum) witnesses to the presence of this event—a non-intuitable QM object (described in L_Q) within the laboratory horizon (described in L_O). Though these two layers of factual representations—in L_O and in L_Q—are different and distinct, each is 'real' and 'observable,' but each requires a differently embodied observer-subject, not capable of functioning simultaneously. Perhaps, the situation is analogous to looking at a photograph, say, of Pike's Peak of the

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[4] A. Einstein, *Out of my Later Years* (New York: Philosophical Library 1950), 64.

[5] The assumption that underlies the Wigner conception of quantum theory as a QM Hilbert Space of (infinite-dimensional state) vectors is that observable horizons are represented by Hermitian operators on the QM Hilbert Space. In this representation, the QM Hilbert Space represents and theoretically defines the vocabulary and grammar of the QM 'real,' i.e., the horizon of the observable quantum world; under which the theory-bound invariances or symmetries are fulfilled within appropriately set up laboratory environments.

frontal range of Colorado's Rocky Mountains: the same embodied viewer cannot simultaneously hold in vision the shiny grey shapes on the flat surface of the photograph and the soaring majesty of Pike's Peak as pictured in the photograph; each can be seen separately, but not together in one visual representation.

In the observer-subject's two distinct tasks—of attending to the 'medium' (the 'horizon' as place and context) and attending to the 'message' communicated by the 'medium' (an event in this 'horizon')—the subjective epistemological points of view as well as the physical embodiments involved in each are epistemologically mutually incompatible. The methodologies of investigation as expressed in research procedures and criteria differ; the cognitive intentions and the subject-object relations differ. The QM object-event is observed only from the point of view of the scientist as the QM observer-subject exploring the QM horizon for events describable in L_Q. The measurement process is described and executed by the same scientist but acting in a different and distinct role from the QM observer-subject which is physically and epistemologically incompatible with the former role. What has happened is that one and the same scientist is able to act on separate occasions as two different and mutually incompatible observer-subjects by choosing two different embodiments, each responding to two different objective horizons described by two different descriptive languages.

(ii b). The union between the sensory organs of the human subject and the external instrumentation is a physical union—but not exclusively physical. Heisenberg, commenting on the relationship of people to their environment in a technological society, wrote:

> "The things by which we are daily surrounded do not thereby belong to nature in the original sense of the word. Perhaps the day will come when the many technical instruments will become as inescapable a part of ourselves as the snail's shell is to its occupant or as the web is to the spider. But even these instruments would be a part of our own organism rather than parts of external nature."[6]

There is, as we have seen, on the one hand, the possibility of a wholeness that unites the object and the instrument and, on the other, the possibility of a wholeness that unites the scientist and the instrument. The welding of the instrument to the scientist becomes, as Heisenberg says, "as inescapable a part of … [the observer] as the snail's shell is to its occupant or as the web is to the spider."

What is the nature of these unions? There are many physical interactions between the human body and the external world which are not (normally)

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[6] PCN, 18.

accompanied by acts of observation, such as breathing, digesting, and using one's feet to walk. These and others, such as cooking, hiking, and singing, can be noticed and become objects for reflection and decision making. The kind of physical union with the external environment that enters into expert scientific observations is analogous to the kind that exists, for example, between a reader and the printed page. The analogy is not a new one. Bacon, Galileo, and Newton attacked the attitude of relying on human authorities in natural philosophy. They assumed—as did their Hebrew-Christian-Islamic culture—that Nature was created by an intelligent being, God, who made it as a Garden in which humans could live and flourish. But how could humans know how to live and flourish in this Garden?

It was argued that God would have provided a way for humans to discover how to live and flourish in this Garden of Nature. They adopted the analogy of a book: Nature was a book, a sacred book, God's own "Book of Nature." From it we learn what we need to know about how to live with one another in Nature's Garden. But if Nature is composed like a sacred text, then it has a literary genre, and one naturally asks: What was its literary genre? God used many different genres in the Hebrew, Christian, and Islamic sacred texts; chief among which are the foundational narratives on which the Hebrew, Christian, and Islamic people came to understand their calling to unite and live as their God's special tribe. These narratives were interpreted in many ways by their tribes—as historical, mythic, legal, poetic texts, or later when numbers came to be associated with alphabetic figures, mathematical interpretations followed that were embodied in musical forms that often accompanied the narratives' interpretation. Much later and in the late Middle Ages of Western Christian culture, Galileo and later Newton and their followers chose to stress the use of mathematics to interpret the Book of Nature and so began the mathematical stories of Nature as the fixed and eternal forms attributed to God's Wisdom who authored God's Book.

The modern mathematical science of Nature arose in the sixteenth century following Galileo's, Kepler's, and eventually Newton's *Mathematical Principles of Natural Philosophy* that unified the Laws of Motion for inertial bodies moving in uniform rectilinear motion until disturbed by the influence of dynamic forces such as the "force of gravity." Side by side with the biblical narratives and the traditions of literature that they inspired, there grew up a new and modern scientific culture that used measurement and mathematical theories to divine the meaning of God's Book of Nature, as both a work of natural science and of Hebrew, Christian, and Islamic theology.

The dominant modern model of objective knowledge is still physics; physics is grounded in the study of Space, Time, matter, and energy. Classical Newtonian physics works so well in constructing our Western everyday human intuitions of

Nature that it was eventually taken to be a kind of 'natural revelation' of religious origin, and as such it flourished for about three hundred years until the emergence of Einsteinian physics and quantum physics that shook the foundational certainties of the classical modern physical and cultural world. From this arose a critique of the notion of *objectivity* insofar as it seemed to express the eternal stability of the mathematical principles of Nature and their independence of human culture and history.

The post-modern turn is then inwards rather than outwards; in the past it looked outwards towards the presumed worldly horizon of eternal stability; post-moderns look away from the natural history of the cosmos and look inwards, back to the human observer's role in constituting the complexity of worlds and worldly horizons and of telling the mathematical stories of Nature as not solely due to God's initiative but also due to the intervention of living creatures. Among these there is the human imagination and human interventions in Nature that has shaped 'horizons' of meaning and then 'Worlds' of meaning. Even spatial and temporal laws that were formerly decreed solely by divine laws have now become human choices and cultural decisions. In the age just past, the God of science was thought to be the unique impersonal author of a mechanical, impersonal life, culture, and the cosmos, ruled by mathematical functions, but now life, culture, and even the cosmos have become the product of creature partners at work, such as in biological evolution, or human partners as in cultural and technological development or in the use of artistic, cultural, philosophical, and theological imagination in giving meanings to the horizons and cultural worlds that humans have made for themselves under the freedom that God has given them.

The classical period of natural science presumed optimistically that God would speak with authority to humans through Nature about how to live together, in accordance with objective laws and with compelling certainty. Now we know that Nature evolves, has made choices on its own, shares freedoms which we humans thought were just ours and not shared with Nature or Nature's God. Evolution, we now think, gives living organisms freedom to make decisions opportunistically. Embodied intelligence gives humans the freedom to explore their embodiments in music, dance, art, and poetry, as well as in tools, technologies, and the legal bonds of community life. In each domain of human activity, humans embody their minds in different media that can give leverage to enhanced productivity in chosen environments, such as medicine and health care, engineering and the exploitation of space and time, communications and community making, farming and the productivity of husbandry, food and the exploration of color and taste, and so on. Natural science has become a partnership with the divine in exploiting the richness the Nature offers to our imagination and choice so that with this freedom we can endow our environment with the meanings we want them to display—for our personal memory, for common festivities, and for love, joy, and peace in our community.

The belief in the absolute authority of Nature's Book ended with the quantum theory of the microcosm, and the relativity theory of the cosmic universe. The founders of the quantum theory—Schrödinger, Heisenberg, Bohr, Wigner, and many of their distinguished colleagues—pointed the finger at the role of human activity in describing the microcosm. Einstein, the founder of the Special and General Theories of Relativity, created further paradoxes that seemed likewise to point the finger at the role of human activity in describing the macrocosm. In both cases the problem is centered on the meaning of measurement, of measure numbers, and of the physical and epistemological context in which measurements are made.

Among the natural sciences, physics has a dominant place as a model because of its history of success in matching mathematical theory to measurements and consequently in generating successful technologies that we use to support and enrich the material cultures of human societies. The complex role of the observer-subject in "reducing" observed-objects to sets of measure numbers is fundamental to the way in which the natural sciences are used within material human culture.

How are these number-signs to be "read"? And what do they reveal about Nature, to whom, in what context or horizon, and for what purpose? Consider the linguistic analogue: communication takes place under ordinary circumstances without inference. Under ordinary circumstances we do not first describe the shapes of letters, or the sounds of words—the linguistic signs—and then use these descriptions as premises from which to infer the meaning intended by the speaker or writer. This is a matter of factual experience and does not, of course, imply that inference is never used in making out the sense of a word or sentence. A description of the sign may precede the understanding of the sign, such as in learning a new language or in decoding a cipher. But in using a language with which we are familiar, the visual or auditory stimuli play the role not of premises but of signals belonging to a communications medium or channel from which the message is apprehended hermeneutically without inference. Sentences are said to "picture" the world, not by being themselves described (with respect to shape or timbre), but by being used correctly within the appropriate shared 'horizonal' context of the same 'world.'

Turning now to 'natural signs,' or rather, to those signs or instrumental responses which a scientist elicits from nature during the course of an experimental investigation, we ask: do these function within an inferential schema, or can they also be used, like linguistic tokens, non-inferentially? Undoubtedly, in certain cases, a scientist could and often does give a detailed description of the instrumental response, e.g., of the width and density and curvature of a photographic image, but he also 'reads' it, for it works like a familiar word or text, the meaning of which is the descriptive statement 'p'—a QM statement. Such a procedure has the immediacy characteristic of an observation. The instrumental response—a number, a trajectory, or a diagram—plays the role here of a signal or communication channel from which a message can be 'read' by an expert observer. The operation of 'observation' is more like 'listening to' music, or 'reading' a text. This is a modern laboratory version of the early modern book-plate of 'making Nature disguised as *Sophia* speak.' To the extent that the instrumental response is used as a signal in a complex communication system, inference is by-passed as a matter of fact, and the descriptive statement 'p' satisfies (i d) above, the condition of immediacy for an observation statement. It is then correct to say "In a measurement one observes that-p."

In the case of language, sentences express the personal intention of the speaker. They also, however, express a certain objective intention, embodied in the language the speaker uses irrespective of whether, as an individual speaker, she knows or intends this objective intention. In the case of the instrument, its 'spoken utterance' lacks a subjective personal intention, but it possesses an objective intention incorporated in the meaning which the scientific community assigns to it on the basis of a physical theory. The instrumental response is both the physical effect and the intentional sign of objects and interactions that are described by a physical theory. The object modulates the state of the instrument so as to produce a signal that can be read by a community of observers as 'an objective statement of fact.' It is clear that such a 'statement' is trustworthy only if there exists a physical theory which explains the character of the signal modulation. In language communication where linguistic tokens are only conventionally connected with the meanings they carry, truth is dependent on correctness of use. In physics, the instrumental response is not conventional and its truth-warrant is its production under a set of circumstances correctly set up on the basis of a physical theory.

A theory of the measuring process then must be a physical theory in that it must account for the modulation of the instrumental channel. It is more than a physical theory, however, for to the extent that instruments become familiar organs for the investigation of the world around us, they lose their character of being mere objects of nature about which human knowledge and action are ultimately concerned and become instead channels of communication between the scientist and his world. To use Heisenberg's terms, instruments cease to "belong to nature in the original sense of nature," they become "part of our own organism rather than a part of external nature."[7] They become, as it were, extensions of our own sensory organs permitting us to observe otherwise imperceptible aspects of nature.

The distinction between the observer and the observed is not, as Heisenberg was well aware, a distinction established uniquely by the physics of the case but one resulting from the choice of the scientist. It is this choice which completes the distinction between what will be treated in the outcome on the analogy of a linguistic sign (e.g., the macroscopic indicator marks in the apparatus) and what will be treated in the outcome as the fact designated by these signs.

(iii) 'Observability' and 'describability' in the natural science require two distinct linguistic frames: the frame L_O (considered as standing in for the more precise L_N, or L_R, see iv below) appropriate for the description of the measurement process and the response of the measuring apparatus, and the frame L_Q appropriate for the description of the QM object about which the apparatus 'speaks.' How are these frames related to one another?

What is the relation between the linguistic frame appropriate to the description of the instrumental response and the one appropriate to the description of the QM object? Although a sign as such is used and not described, it may, for the purposes of making an inference, be described. In such a case, it becomes a thematized fact described in some linguistic frame. Let us call it a *sign-fact*. It is linked to a *signified fact* described perhaps in some other linguistic frame. In this case the signified fact is the QM object-event. What relationship did Heisenberg suppose existed between the descriptive frame of the *sign-fact* and the descriptive frame of the *signified QM fact* when a QM observation is made?

Consider the activity of describing an instrumental response (e.g., the position of an indicator or a photographic track). A lay person uninstructed in science can observe and describe the instrumental response as a *sign-fact*. Such a person would most probably use L_O for the description. However, lacking scientific training this person cannot interpret the sign-fact and, therefore, cannot observe or describe or infer the nature of the QM object-event recorded by the instrument. The trained scientist, on the other hand, can infer the nature of the QM object, and she can also observe and describe it. Because of her familiarity with the instrumental set-up she can even observe and describe the QM object without having to derive the nature of this event by inference from a prior description of

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[7] PCN, 18.

the sign-fact. However, she has to begin with the recognition of the instrumental response as a sign of the local presence of the signified QM object.

Heisenberg and the Copenhagen Interpretation claim that the predicates descriptive of the instrumental response (the *sign-fact*) and of the QM object-event (the *signified fact*) do not go beyond the combined resources of L_O and L_N. Not that the languages descriptive of quantum mechanical events are just subsets of L_O or L_N, for something new and non-classical is being asserted about nature, something that at the same time exceeds the capacity of L_O or L_N to describe it. What can be known about such *non-classical objects* is merely that they are a *function of classically describable phenomena*. QM descriptive language is then conceived in the Copenhagen Interpretation not as a picturing language properly descriptive of the inner structure and dynamics of QM objects and events, but as a new—and *hermeneutic* (interpretive)—way of using L_O or L_N (metaphorically?) to make correct assertions about non-classical QM objects and events.

Apart from, say, the dogmatic assertion that human conceptual resources cannot transcend the descriptive capacity of everyday language and its idealizations, there is the argument that a scientific claim be formulated in a publicly objectifiable fashion. The *public or intersubjective character* of a scientific claim ought to be distinguished from the *objectifiability* of the scientific claim. A public claim is one that can be intersubjectively tested. *An objectifiable claim is one to which an observer contributes nothing, neither to the production of the physical fact nor to the description of that fact.* The paradigm case of objectifiability is classical physics. Classical systems are closed isolated systems, and classical concepts are logically unrelated to instruments or measuring process interactions. A scientific claim must certainly be public; but not every public claim need be objectifiable in L_O or L_N. What is asserted may well be the undisclosed meaningful structure supported by the act of measurement, one in which the *QM-observer finds a new and public meaningful fact, namely, the QM-observed in the public output of measurement.* Measurement then becomes the public medium, the function of which is to disclose the presence of local, theoretically named, structures and functions not accessible otherwise to human sensory experience. The instrumental response is the medium channel through which the scientific content is made public.

The instrumental response must be objectifiable to perform its communication-theoretic task efficiently. Ambiguity or uncertainty in this channel results in what information theory calls “noise”; this interferes with the unambiguous transmission of messages coded on neighboring sign-facts. Ambiguity of this kind does not affect the meaning of the messages carried by the signs, only the ability of an interpreter to pick out clearly and unambiguously which one of a bundle of messages was intended by the source. Publicity and objectifiability belong to the channel as described, that **is,** as a manifold of sign-facts.

The QM object also has the property of publicity, but not of objectifiability. The non-objectifiability of the QM object implies in the Copenhagen Interpretation the non-describability of the QM object. How can the QM object, however, become an object for discourse if it cannot be described? We propose that the answer is in choosing to regard the predicates of the QM object as metaphorical with respect to the predicates of L_O or L_N, or dispositional relative to the objectifiable information-theoretic events that are describable in L_O or L_N.

(iv) What is the relation between the everyday descriptive linguistic frame L_O and the descriptive frame of classical physics L_N?

It has been argued by Bohr and Heisenberg that the descriptive language of classical physics, with its precision and objectifiability, represents a limit to the human power to conceptualize and describe nature. They allege, moreover, that the language of classical physics is an "idealization" or a "refinement" of the everyday pre-theoretical descriptions of nature. What seems to be implied by this claim is that physical predicates of L_N have the same meaning as everyday predicates of L_O but are used with greater precision in L_N. It is implied, moreover, that this is so, not merely as a matter of fact, but because a philosophical study of our powers of knowing demonstrates that it could not be otherwise. Heisenberg seems in his Gifford Lectures, 1955–56, to have abandoned this dogmatic position in favor of a more historicist view, namely, that ordinary language is the product of a historical cultural process analogous to the evolution of a natural biological form.

But to return to the statement that L_N is an "idealization" of everyday pre-theoretical usage: this is undoubtedly true of the language used by modern Western culture. The norms of everyday usage in describing kinematical and dynamical states of affairs are those of classical physics. This can be easily demonstrated. Consider the Müller-Lyer optical illusion (see figure 2).

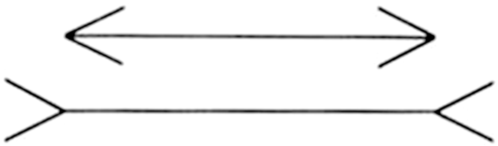

Figure 2. Müller-Lyer Illusion.

If somebody judges "with an innocent eye" that the two lines are of unequal length, she can be brought to acknowledge that her judgment was mistaken by being shown that the two lines have equal *measured* lengths. Evidently, ordinary language in our culture is governed by the normative procedures of classical physics.[8] This is a matter of linguistic convention in our society, but it is not the only convention which a community could adopt. A different convention might be proposed and adopted, say, by a group of artists, such as Van Gogh and the post-impressionists, who decide to judge relative lengths, sizes and distances by a purely visual binocular comparison of the object from the standpoint of where the artist stands. Using a small number of very simple and plausible assumptions, it can be shown, as Luneburg has done, that the geometry of space will be non-Euclidean, and negatively curved.[9] I too have studied with colleagues in psychology the way a Euclidean world (correctly described in L_N) would appear to one of this community of artists and I have shown that the spatial relationships she would observe, anomalous according to our usual conventions, do correspond well to the peculiar spatial relationships painted by Van Gogh and Cézanne. Is it not plausible to suppose that Van Gogh and Cézanne did just what I said, proposed to themselves and adopted a new and different spatial language, based naturally on purely binocular visual comparisons rather than on the transportation of rigid rulers? The new non-Euclidean geometrization is unrelated (except topologically) to the old, nor is the new geometry simply a re-coordinatization (or re-description) of the old in which infinitesimal lengths are conserved. The structure of space privileges the nearby zone of eye-hand coordination and its farthest horizon is a finite dome like the starry heavens we see at night.

The possibility of such new geometrical conventions demonstrates that spatial language is not restricted to the a priori of classical physics. If L_O accepts the norms of L_N, it is not because L_N expresses more precisely what a primitive pre-theoretical L_O expressed, but because, since the Scientific Revolution, L_N has come to be preferred in the West as normative over older spatial conventions.[10]

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[8] That a geometry of the real world is the conjunction of a formal geometrical system and a (physical) rule of congruence is emphasized by A. Grünbaum in his classical *Philosophical Problems of Space and Time* (New York: Knopf, 1963), chap. iv.

[9] For the study of binocular visual space, cf. R. K. Luneburg, *Mathematical Analysis of Binocular Vision* (Princeton: Princeton Univ. Press, 1947): considerable work has been done on the non-Euclidean character of binocular visual space. [See n. 189 below.]

[10] W. Yourgrau comes to a similar conclusion on the basis of studies made by Piaget, Inhelder, Revesz and others of the "haptic space" of young children (constructed by exploring objects through touch). See, for example, his "Language, Spatial Concepts and Physics" in *Mind, Matter and Method,* ed. by P. K. Feyerabend and G. Maxwell (Minneapolis: U. of Minnesota Press, 1966), 492–505.

The dependence of everyday language on a historical process was later recognized by Heisenberg. It grew, he said, as a means of more or less unambiguous communication about events in daily life and as a basis for thinking.[11] Moreover, it is ever growing and changing. It is the exclusive home of what we call the "real." Reality, being the objective of everyday descriptions, changes with the changes in everyday language. When relativistic space-time was absorbed into common language, the description of reality changed. Heisenberg's early proposal to reinterpret the kinematical variables of physics was not, however, absorbed by common language. Instead, the paradigm of complementarity was embraced which did not change or add to the descriptive predicates of nature but merely claimed to control their applications by a higher logic. The alternative to complementarity that Heisenberg later chose is the development of a precise though non-classical logic to replace the Aristotelian logic pre-supposed by ordinary language. In this connection he endorsed the work of Birkhoff and von Neumann and C. F. von Weizsäcker.[12] We shall return to this matter below.

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[11] PP, 168; AHQP, Heisenberg-Kuhn, 27 February 1963.

[12] PP, 181–86.

CHAPTER TWELVE

The *a Priori* Role of Classical Physics

The effect of all these limitations of viewpoint can be seen in that central thesis of the Copenhagen Interpretation: classical physical concepts play the role of a privileged a priori in quantum physics.

Heisenberg held that it was a necessary condition for objective science, that experimental arrangements and their results should both be describable in everyday language or in L_N. But what did he mean by "experimental results"? Bohr, it seems, meant the empirical instrumental readings—the measure-numbers—responsible for the "sensory objects" which are the cognitive terms of a quantum mechanical observation.[1]

We have already seen that, in the case of Heisenberg, the logic of the principle of implicit definition would oblige him to say that when classical concepts are used for the description of the results of a quantum mechanical experiment, they can do no more than describe the instrumental reading, since the quantum mechanical object is not a classical object. In a quantum mechanical observation, the instrumental reading is the 'phenomenon' (in a Kantian sense) relative to the 'noumenal'

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[1] Bohr, ATDN, *op. cit.*, 1, 5, 8, 16f, 53. Cf. P. Feyerabend, "Complementarity," *Proc. Aristot. Soc., Suppl.* **32** (1958): 75–104, where he summarizes Bohr's view in the following way: the microscopic object is "now characterized as a set of (classical) appearances only, without any indication being given as to its Nature," 94.

quantum mechanical object. This interpretation seems to be borne out by his later explicit treatment where the echoes of Bohr are clearly heard.

In a lecture he delivered at the University of Vienna in 1938, Heisenberg said:

> "The concepts of classical physics will remain the basis of any exact and objective science, because we demand of the results of science that they can be objectively proved (i.e., by measurements registered on suitable apparatus) and we are forced to express these results in the language of classical physics. Thus, while the *laws* of classical physics appear only as limiting cases of more general and abstract connections, the *concepts* associated with these remain an indispensable part of the language of science without which it would not be possible ever to speak of scientific results."[2]

The experimental results in question—the instrumental readings—describable by classical concepts are, of course, B-observable events.

Heisenberg later associated the notion of *actuality*, of a really existing event, exclusively with B-observable states of affairs. "The Copenhagen interpretation is indeed based on the existence of processes which can be simply described in terms of space and time, i.e., in terms of classical concepts and which thus comprise our 'reality' in the proper sense."[3] However, he says elsewhere, that this conclusion "apparently finds itself somewhat opposed to the experimental situation in the atomic field and to the quantum theory. It is precisely here that this unequivocal determinateness of events is questioned."[4] From the context, it is clear the events he means are quantum mechanical object-events, taken as *signified facts*, implying that the instrumental readings are *sign-facts* that *signify but do not describe* the *quantum event*. Then he continues: "Why is it not possible to transform the whole physical description to a new system of concepts based on the quantum theory?" It was with just this goal in view—to postulate L_Q—that Heisenberg wrote his first paper on quantum mechanics. Thirty-three years later, he quotes Bohr, "the concepts of classical physics—like the a priori forms of perception in the philosophy of Kant"—[*phenomena*]—"form an a priori basis for experiments in quantum theory, because we can conduct experiments in the atomic field only by using these concepts of classical physics."[5] The quantum events were *unimaginable* "*noumena*" to the "*phenomena*" of instrumental readings.

With his conversion to complementarity in 1927, Heisenberg gave up his belief that quantum mechanics could reveal the descriptive ontology of atomic objects

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[2] PPNS, 45. See also PP, 44, 144.

[3] W. Heisenberg in "Development of the Interpretation of the Quantum Theory," in NBDP, 28.

[4] Heisenberg *et al., On Modern Physics* (New York: Collier Books, 1962), 18–20, 44.

[5] *Ibid.* 18–19.

and joined Bohr in taking quantum mechanics to be a science of the macroscopic environmental effects (space-time events of a classical sort) produced by the presence and interaction of atomic objects with macroscopic measuring instruments.

Was there any alternative to the complementarity approach? Some reflection on the history of science would have shown that practically all of the great natural philosophers in the Western tradition subscribed to some form of the principle of E-observability: Einstein, Maxwell, Newton, Kepler, Galileo, Copernicus, da Vinci, Archimedes.[6] When Heisenberg returned to the question later in life as to the descriptive content of quantum mechanics, he sought in the history of philosophy for a term to describe the ontological status of such E-observable situations as the quantum mechanical state of an isolated system or an elementary particle considered as a stationary state of a fundamental matter equation. In keeping with the Aristotelian character of complementarity, he found the term he was looking for in Aristotle: *potentia* ("potency").

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[6] Most recent 'objectivist' or 'realist' interpreters of quantum mechanics other than 'hidden variable' theorists, base their views on some form of a principle of E-observability, e.g., Popper and Bunge. See *Quantum Theory and Reality*, ed. M. Bunge (New York: Springer-Verlag, 1967), especially Bunge's "ghost-free axiomatization of quantum mechanics," 105–17, and Popper's, "Quantum Mechanics without 'The Observer'," 7–44.

CHAPTER THIRTEEN

The Gifford Lectures 1955–56 and the New Aristotelianism

The Gifford Lectures[1] of 1955–56 marked a turning point in Heisenberg's philosophy back to the principle of E-observability as the ontological criterion and to a more rationalistic interpretation of complementarity. His conviction remained, however, that 'reality,' in the truest sense of actuality, was still conditioned by B-observability, but he found a reduced epistemological role for E-observability. This was a natural development for someone of Heisenberg's temperament, for he had never repudiated the belief that scientific conceptual frameworks were revisable. The evidence of relativity was before his eyes. The fact that he was not able to support his original contention that quantum mechanics called for such a revolution did not shake his belief that such revolutions were possible and had in fact happened.

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[1] The Gifford Lectures were given at the University of St. Andrews, Edinburgh; the English text was published in the World Perspectives Series under the title *Physics and Philosophy* (New York: Harper and Row, 1958). The German version *Physik and Philosophie* was published by Ullstein Bücher, Frankfurt am Main, 1959.

The fruit of his earlier long discussions with Bohr, helped possibly by the later influence of Martin Heidegger,[2] led him to realize that the scientific community plays a role in defining what is taken to be ontologically real, and that this was done through language. Ontological reality—in the new Heideggerian sense—is the domain of what can be objectively (i.e., publicly or intersubjectively) observed and described. The objective meanings of the terms 'reality' and 'ontology' were then as much related to a linguistic community as, say, to scientific theory and observation. *Ontological Reality*—in Heidegger's sense of *Dasein*—being the most public of domains waits on the consent of the public to admit changes in conceptual and linguistic usage. To change the meaning of 'reality' then new linguistic *conventions* have to be adopted, but if the community refused to do this, then a temporary expedient might be adopted, say, to use the old language in a new way. This was how Heisenberg in his Gifford Lectures described the philosophical predicament in which the quantum theory placed the scientific community.[3] Complementarity he concluded was such an expedient. The scientific community adopted it rather than follow the paradigm of relativity. Its lifetime of thirty years and more of service proves that it was not an unsatisfactory expedient for many scientific purposes. There was, however, the possibility of another and better solution.

The Gifford Lectures marked Heisenberg's return to the germinal principles of his original insight, namely, to the *principle of E-observability* ("Whatever is E-observable belongs to the descriptive ontology of nature"), and to the *principle of implicit definition* ("In the case of a physical theory, the descriptive concepts are defined by and through the mathematical physical theory"). The latter principle serves to define the new descriptive concepts of quantum mechanics. The former justifies the proposal made to the scientific community to accept the new concepts as the bearers of the new descriptive ontology of the atomic and subatomic domain. To get such new concepts accepted, however, involves persuading people not only that the new linguistic conventions were better in their descriptive value than the old, but that they are better also in practical matters. In the lecture "Language and Reality in Modern Physics," Heisenberg set out to discuss some of the implications of this view.

Three points have to be considered: (a) What kind of ontological status is to be given to E- observable terms, especially to what is represented by the state-vector

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[2] Heidegger was a German hermeneutical and phenomenological philosopher with whom Heisenberg was in regular and friendly conversation, and in whose honor he wrote an essay "*Grundlegende Voraussetzungen in der Physik der Elementarteilchen*," *Martin Heidegger zum siebzigsten Geburtstag: Festschrift* (Pfullingen: Neske, 1959), 291–195.

[3] PP, chap. x, "Language and reality in modern physics," 167–86.

(or wave function) of the atomic system? (b) What is the logical character of quantum mechanical descriptive predicates? (c) What is the sentential logic of the language that uses quantum mechanical descriptive predicates?

When the principle of B-observability is used as an ontological criterion, it limits the 'of the world to localized space-time events describable in L_O or L_N. These events Heisenberg continued to call 'real.' In the Gifford Lectures and later they were "real in an unqualified sense" ('*Realität*'),[4] 'real in the Lectures true sense' ('*wirklich real*'),[5] 'act' or 'actuality' ('*Aktualität*,' '*Wirklichkeit*').[6] The last term best describes the reality of those events mediated by the principle of B-observability. To be actual, however, an event, in addition to satisfying the principle of B-observability—a necessary condition—has to satisfy one of the following conditions: (1) to have been actually described or (2) to have been actually recorded by an instrument while being at the same time an event of a kind describable—and eventually to be described—in the terms of L_O or L_N. The fulfillment of either of those conditions is sufficient to warrant the fact that the system has been observed.

Unlike a classical system, the state of a quantum system antecedent to an observation does not in general coincide with its state after being observed; the observation actualizes one of a set of possible states of the system and communicates this event by actualizing the corresponding classical signal (sign-fact.) This outcome includes some positive, objective (in the sense of publicly-accessible) elements, such as its wave function (or state vector), which changes, however, in time according to its Schrödinger equation. But the wave function is *incomplete* as a description of an *objective actuality* in L_N and L_R. Since subjectivity and objectivity are correlates,[7] the deficiency of objectivity is said by Heisenberg to contain subjective elements.[8] The *subjective elements* in the description are: (1) *ontologically*, its relativity to a set of possible but mutually exclusive observers (measuring environments); (2) *logically*, the fact that for any of these observers, no more can be predicted prior to an observation than the probability distribution of the possible

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[4] For example, W. Heisenberg, *Physik und Philosophie*, *op. cit.*, 25.

[5] For example, see W. Heisenberg, *On Modern Physics, op. cit.*, 19.

[6] *Physik und Philosophie, op. cit.*, 25, 106, 118. *Physics and Philosophy*, *op. cit.*, 130, 144–45, 200; *On Modern Physics, op. cit.* passim.

[7] 'Objectivity' and 'subjectivity' have a variety of meanings. These constitute different contrasting extremes under a variety of aspects, such as public vs. private, truth vs. supposition, external vs. internal, unbiased vs. biased, etc. A lack of objectivity in one respect is an increase of subjectivity in that respect. Cf. P. A. Heelan, *Quantum Mechanics and Objectivity, op. cit.*, chap. v.

[8] PP. 41, 53, 9–71, 91, 130, 144, 148, 180, 185; PCN, 14–15;NBDP, 25–28; W. Heisenberg, *On Modern Physics, op. cit,* 9–10, 16, 19.

event outcomes; (3) *linguistically*, our profound ignorance of any set of descriptive predicates that can be exemplified in the quantum system prior to the specification of an observer.

Heisenberg has illustrated (2) and (3) by a comparison with classical statistical thermodynamics.[9] Given an observer and a quantum system, for that observer to say antecedently to an act of observation that its wave function is ψ, is like someone saying of a classical system that its temperature is T° C, for to say of a system that it is T° C is to say no more than that the system is a member of a canonical ensemble of systems with different energies distributed according to a certain probability distribution. Moreover, to state of a system that it has a certain (definite) energy entails that its temperature is quite indeterminate. There is an important difference, however, between the thermodynamic case and the quantum mechanical case. In the case of temperature, each individual system of the ensemble has an actual precise energy antecedent to observation and a precise microscopic description. In the quantum mechanical case, however, there is no set of descriptive predicates (microscopic or otherwise) in terms of which the system has a definite description antecedent to the specification of an observer, while even after the specification of an observer, it is in general not the case that the system is in a definite eigen state vis-à-vis the observer antecedently to actual observation.

Antecedently to observation, a quantum mechanical system is described by a wave function. What is the ontological status of the system that is so described? In the complementarity interpretation, the wave function is just one of the mathematical tools we use and it is not part of a description of nature. This was the view which Bohr held and to which Heisenberg agreed in 1927. But in his Gifford lectures of 1955–56, Heisenberg adopted for it the Aristotelian term 'potency,' or '*potentia*' ('*Potentialität*') a translation of Aristotle's δύναμις.[10] He also used almost as synonyms, 'possibility' ('*Möglichkeit*'),[11] 'objective tendency' ('*objektive Tendenz*')[12] and 'probability' ('*Wahrscheinlichkeit*').[13] In Aristotle's philosophy, a *potency* is a metaphysical principle that by definition is ordered to its corresponding *act* or *actualization*. It is either a passive desire for its act (a passive potency), or a power to perform its act (an active potency). In either case, it gets its meaning and definition from the goal it envisages. *Potency* then is denominated (gets its

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[9] NBDP, 23; PP, 180.

[10] W. Heisenberg, *Physik und Philosophie,* 25, 36, 151; *Physics and Philosophy*, 41, 148, 180; NBDP, 13; *On Modern Physics*, 9–10, 16.

[11] W. Heisenberg, *Physik und Philosophie*, *op. cit.*, 24, 51, 146; NBDP, 12–13.

[12] W. Heisenberg, *Physik und Philosophie*, *op. cit.*, 25, 34, 36, 51, 156; PCN, 15; *On Modern Physics, op. cit.*, 16.

[13] W. Heisenberg, *Physik und Philosophie*, *op. cit.* 25. 36; *On Modern Physics, op. cit.,* 16.

definition) from *act* and not *act* from *potency*. Both forms of potency achieve their completion and fulfillment with the actualization of the corresponding act.

The kind of *act* in relation to which the quantum mechanical system is defined, is the kind of spatio-temporal B-observable event that results from an observation. The wave function (statistical matrix, or state-vector in Hilbert space) which is the mathematical part of the description of the QM system and which describes the QM potency, has more of the character of an *active potency* than a *passive potency*, for it is a power or tendency to act on an observer so as to produce certain well-defined events with a definite frequency.

As for the ontological status of *potency*, Heisenberg calls it "something in the middle between the idea of an event and the actualization of the event, a strange kind of physical reality in the middle between possibility and actuality."[14] Elsewhere he describes its ontological status as "a certain intermediate layer of reality, half-way between the massive reality of matter and the intellectual reality of the idea or image."[15] In the complementarity interpretation, the wave-function is merely a mental construction and not part of a description of nature. In the new Aristotelian ontology, its descriptive though non-classical role is acknowledged, but it is not a reality-in-act, but a reality-in-potency.

One of the consequences of Heisenberg's return to Aristotelian philosophy is that he can give an ontological status to the wave function. He introduces E-observability as an ontological criterion for what Aristotle would have called "a metaphysical principle of being." The wave function then is an active potency, which, for Aristotle, is *form; form* unites with *matter*—*materia prima* or *fundamental matter*—to generate *being*, which is the object of ontological studies. Heisenberg takes this *fundamental matter* to be energy.[16] The isolated quantum mechanical system is then antecedently to observation a *potentia* (*activa*) constituted by its *form* (which is the state-vector or wave function), and *matter* (which is energy). Its *acts* (or actualizations of *being)* are those modifications of the environment which constitute the set of B-observable events. A *potentia*, however, is not *actual* (not truly *being* but only a *metaphysical principle of being*) since these terms are associated (by convention) with everyday B-observable states of affairs describable in L_O or in L_N. Since this reality is 3-dimensional, the

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[14] PP, 41.

[15] Heisenberg, *On Modern Physics*, *op. cit.*, 16.

[16] PPS pp. 61–63, 160, 166; PCN, 43–46; *On Modern Physics*, *op. cit.*, 16; W. Heisenberg, "*Grundlegende Voraussetzungen in der Physik der Elementarteilchen*," in *Martin Heidegger zum siebzigsten Geburtstag*: *Festschrift* (Pfullingen, Neske, 1959), 291–97. Cf. also PPNS, 53, 95, 106 and his work on elementary particles.

3n-dimensional wave function (for n-particle systems) cannot represent a reality in the ordinary sense of the term.[17]

The notion of *potentia* can be illustrated through the phenomenon called "the reduction of the wave packet."[18] A distinction has to be borne in mind. In the complementarity paradigm, an atomic system can be visualized either as a localized particle or as a 3-dimensional wave packet; as a wave packet it is spread out in space and time and capable of interference and diffraction like an electromagnetic wave pulse. The particle picture and the wave packet picture are just helpful analogies. The wave-packet of the complementarity paradigm is not, however, to be identified with the ontological potency about which we have been speaking.

The ontological potency is the 3n-dimensional Schrödinger wave function $\psi(q_1, q_2, \ldots q_{3n})$ considered as the description of an ontological structure. When an observation of the atomic system takes place, say, at time t_o, the potency is actualized and converted into a description of a classically describable measurement event in which the quantum mechanical system is made present to the observer by this event. Immediately following the moment t_o, the system has a new wave function, say, φ_o, the eigenvector of the observed quantity. The new φ_o represents a new potency; in succeeding moments it will change continuously subject to the Schrödinger equation of the system. The change in representation from ψ to φ_o following an observation is a discontinuous change and is called "the reduction of the wave packet."

Some comments on Heisenberg's philosophy are called for here.

1. *From the point of view of a descriptive ontology, the wave function represents a qualified kind of reality, a reality-in-potency* (not a reality-in-actuality). In Aristotelian philosophy, it is a metaphysical principle of being, like a substantial or accidental form constituted by its natural tendency towards its proper act or goal. This represents the objectivist aspect in Heisenberg's philosophy, the one that corresponds to such statements as "The physicist must postulate in his science that he is studying a world which he himself has not made and which would be present essentially unchanged, if he were not there."[19]

   Unlike its Aristotelian counterpart, however, the QM potency is not fully specified with respect to its goal; part of the specification of its goal comes from the observer (or environmental conditions). Moreover, given a fixed observer (with a definite set of environmental conditions), it is still not specified as

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[17] NBDP, 24–25.

[18] PPQT, preface, 39; NBDP, 23.

[19] NBDP, 25.

a unique goal but only to a set of possible goals, and it is specified only by a schedule of probabilities for the actualization of those goals. Hence the wave function as representing a potency also shares some of the aspects of a passive potency, not merely vis-à-vis its own actualization (like any active potency) but also vis-à-vis further formal specification.

2. *From the epistemological point of view, however, Heisenberg put an emphasis on the structure and limitations of human knowledge, since he held with Bohr that only such states of affairs as can be described in L_O or L_N can be known as they really are.* Consequently, when observing an atomic system, the content of that observation (what is describable in what is observed) is a phenomenal content (in the Kantian sense) since one is restricted to what can be described in L_O and L_N, while the quantum mechanical system (as *noumenon*) cannot be so described. The doctrine of potency attempts to go beyond and behind the phenomenon in order to arrive at the objective conditions of possibility of that experience. In this light the potency is a product of *typical post-Kantian thinking*, and represents that aspect of Heisenberg's philosophy revealed in such statements as: *"The new mathematical formulae no longer describe nature but our knowledge of nature,"*[20] or

> "… it is first of all necessary to stress as von Weizsäcker has done, that the concepts of classical physics play a role in the interpretation of the quantum theory similar to that of the a priori forms of perception in the philosophy of Kant. Just as Kant explains the concepts of space and time or causality a prioristically, in the sense that they already formed the conditions of all experiences and could therefore not be considered the result of experience, so also the concepts of classical physics form an a priori basis for experiments in quantum theory, because we can conduct experiments in the atomic field only by using these concepts of classical physics."[21]

C. F. von Weizsäcker was a post-Kantian philosophical thinker. Heisenberg's endorsement of his writings on quantum mechanics implies Heisenberg's openness to this approach.[22]

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[20] PCN, 25; cf. also PPNS, 93.

[21] Heisenberg, *On Modern Physics, op. cit.*, 18–19. C. F. von Weizsäcker is the distinguished physicist, and professor of Philosophy at the University of Hamburg. His principal work on the philosophy of physics is *Zum Weltbild der Physik* (Stuttgart: S. Hirzel, 8th ed. 1960).

[22] PP, 181.

CHAPTER FOURTEEN

The Logical Status of *Potentia*

Central to Heisenberg's notion of *potentia* are then: (1) its ontological status as an Aristotelian principle of being; (2) its logical status as a descriptive dispositional term.

To possess a disposition is not to be in a particular state but to be bound, or liable to be in a certain state, or to undergo a certain change of state (if certain conditions are realized).[1] Consider, for example, the term "soluble." The sentence "This lump of sugar is soluble" is true if and only if, were this lump of sugar to be placed in water (under standard conditions of temperature and pressure), it would dissolve. "Solubility" is defined in terms of an end-state, the state of being in solution, which would result if certain conditions were fulfilled. As far as descriptive language goes, no more is required of it than the ability to describe the end state when the appropriate conditions are fulfilled.

Moreover, the use of a dispositional predicate is equivalent to the use of a counterfactual or law-like hypothetical statement form. This permits, for example, the dispositional soluble to be predicated of a lump of sugar, even though the lump of sugar has never actually been subjected to the test of solubility. In fact, the form of the counterfactual supposes that the test has not been made on the

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[1] Cf. G. Ryle, *The Concept of Mind* (London: Hutchinson, 1949) and N. Goodman, *Fact, Fiction and Forecast* (New York: Bobbs-Merrill, 2nd ed. 1965) and a wide literature.

lump of sugar.[2] It says what *would* happen, if the lump of sugar *were* placed in water. The example illustrates one of the logical aspects of a quantum mechanical *potentia*: its logical dependence on a pre-quantum-theoretical descriptive frame for the description both of the end-state and of the measurement that would bring this end-state about. For just as solubility is denominated with reference to a kind of event, viz., the state of being in solution, which would be actualized if certain conditions were realized, so a quantum mechanical *potentia* is denominated with reference to the event (or set of events) which would be actualized if the system were observed by a specified observer. In the case of the quantum mechanical system, however, instead of one end-state, there is a double manifold of alternative end-states open to it: there is the multiplicity of possible observers and there is the multiplicity of different manifolds of observable events, one manifold for each observer. Both the manifold of observable events and the manifold of observers are, it is claimed, describable in L_O or L_N. The kind of extrinsic denomination we are concerned with here, where the potential end-state enters into the definition of the initial state, is characteristic of a teleological explanation.

Every counterfactual statement, however, assumes or implies or entails that there is an underlying structure or lawfulness which is its warrant.[3] That sugar is soluble in water involves that there is something, for example, about the molecular structure of sugar which explains why it dissolves in water. The dispositional predicate ‘soluble’ involves the existence of a non-dispositional quality in sugar in virtue of which, given a water environment, sugar dissolves in water. To take another example: to say “If Germany had won World War II, the first astronaut on the moon would have been German” is at least to imply that Germany would have had great scientific and industrial capability. Just as every teleological explanation supposes at least the possibility of a non-teleological account in terms descriptive of the underlying structure and dynamics of things,[4] so every counterfactual supposes the possibility at least of an account in non-dispositional terms of the

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[2] Cf. J. A. Eisenberg, “The Logical Form of Counterfactuals,” *Dialogue,* 7 (1969): 568–83.

[3] There are a variety of views as to whether a statement that a thing possesses a disposition entails that the thing (or the thing plus its environment) possesses an intrinsic non-dispositional cause of the disposition or whether this latter claim says more than can be logically inferred from the disposition statement. Cf. R. Harré, *Introduction to the Logic of the Sciences* (London: Macmillan, 1963).

[4] A teleological relationship is sometimes taken merely as an inverted causal sequence (e.g., E. Nagel in *The Structure of Science*). But I am using the term “teleology” more in the way Galileo used it when he criticized Aristotle for neglecting the underlying structure and dynamic which makes a teleological connection possible.

relevant features of the underlying structure and dynamics of things that explain the fact of the disposition.

However, if Heisenberg is correct, a quantum mechanical *potentia* is an exception to this rule. For although a *potentia* is a disposition extrinsically defined relative to its classically described *acts*, it has no intrinsic qualitative predicates of its own, at any rate none that are accessible to human study. Even Aristotle, for whom the paradigm of scientific explanation was teleological, did not despair of trying to show the relation between proper structure and goal.[5] Moreover, modern science developed in the seventeenth century out of a conversion of interest from goalward dispositions to the structural and dynamic patterns that make these goals possible.[6] To claim then that the human scientific capability with respect to quantum mechanical systems is restricted to that of knowing goals and dispositions towards goals, but that it does not extend to the proper structure or dynamics that makes these goals possible for the system and for the observer is implausible in the light of the history of science, and any alleged proof would have to be examined very critically.

Among the first to hold that quantum mechanics in the Copenhagen Interpretation did not give a complete account of the atomic system was Einstein.[7] He held that the quantum mechanical description of an atomic phenomenon, restricted by the Uncertainty Relations, was only a partial and incomplete description of the real phenomenon. He then postulated that there was a subquantum level of determinate but hidden variables which controlled the quantum level and explained its indeterminacies. Einstein, Podolsky, and Rosen, moreover, tried to show in a famous paper[8] that the very formalism of quantum mechanics itself, when combined with a relativistic principle of localizability, entailed that each atomic system must really possess three classically determinate position coordinates and three classically determinate momenta independently of observers, observation, and measurement.

Certain philosophical values were involved here. Einstein, by this time, had repudiated Machian positivism and operationalism that had earlier influenced

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[5] For example, in the *Metaphysics,* 1013a, among the meanings of "cause" is "form or pattern, i.e., the definition of the essence and the classes which include this (e.g., the ratio 2:1 and number in general are causes of the octave) and the parts included in the definition."

[6] Cf. A. E. Burtt, *The Metaphysical Foundations of Modern Physical Science* (London: Routledge and Kegan Paul, rev. ed. 1931).

[7] Cf. *Ibid.*

[8] A. Einstein, B. Podolsky, and N. Rosen, "Can Quantum Mechanical Description of Physical Reality be Considered Complete?", *Phys. Rev.*, ser. 2, **47** (1935), 777–80. See CDQM, 366–70, 387. For a survey of the hidden variables controversy, see, J. S. Bell, *Rev. Mod. Phys.,* **38** (1966): 447.

him in the construction of the special theory of relativity and which he thought he found in Heisenberg's early thinking.[9] He had come to adopt the position that the correct descriptive ontology of nature is given by a mathematical physical theory which, although requiring measurement and observation for its justification, claims to picture physical objects, not as physically linked to observers in the act of measurement, but as systems isolated (physically) from observers. He wrote in his *Autobiographical Notes*, "Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed."[10] In other words, from the logical point of view, he held that it was necessary for physics, in its account of physical objects, to go beyond the intelligible dimensions of an observer-object measuring interaction, to an account of *what things are like prior to and independently of observation.*

There were three aspects then to Einstein's criticism of the Copenhagen Interpretation: (1) an ontological aspect, according to which *only* those theoretical variables that could be said to have precise numerical values were candidates for inclusion among real descriptive quantities; (2) a methodological aspect—his criticism of agnosticism about (what according to his own criteria was) the real state of the quantum system. From these two aspects a third was derived: (3) the general criticism of the role that probability and probability-waves (namely. the wave function in the Born-Pauli interpretation) played in the Copenhagen Interpretation of quantum mechanics.

A classical probability is a measure (interpreted as a relative frequency) on a sample space of events (or propositions) defined and distinguished through the use of a determinate set of descriptive variables. In the Copenhagen Interpretation antecedent to the specification of the QM observer, there is no set of non-dispositional predicates applicable to the quantum mechanical system, and consequently, there is no sample space and no probability measure. A sample space and a probability measure come into existence only when a QM observer is specified. The lack of a universal sample space independently of observers, by means of which the probabilistic aspect of quantum mechanical events might in principle be explained, offended Einstein's sense of what constitutes a rational account of nature. He saw in the Copenhagen Interpretation both a radical abdication of human reason and the claim, which he believed false, that lawfulness was radically absent from nature

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[9] For Einstein's repudiation of Mach's philosophy, see his "Autobiographical Notes," in *Albert Einstein: Philosopher-Scientist*, *op. cit.*, p. 49. Heisenberg recounts his conversations with Einstein in TG, 85–100 and in AHQP, Heisenberg-Kuhn, 15 February 1963.

[10] A. Einstein, "Autobiographical Notes," *Albert Einstein: Philosopher-Scientist, op. cit.*, 81.

and that “God throws dice” to decide what should happen.[11] Einstein’s counter claim was that the quantum mechanical system should at all times be the subject of a well-defined set of descriptive predicates, the so-called “hidden variables” of the quantum mechanical system.

Perhaps, a distinction can be made between, (1) the representation (or model) of the QM ontology and (2) the ontological reality that is so represented (or modeled). The further question then has to be posed: what is the nature of the QM ontology that is so represented, and how is its scientific reality related to its independent ontology, its ontology *tout court?* How does such an ontology function in the scientific world? Einstein rejected such a distinction; his claim was that the ontology *tout court* of a QM system must be describable by a set of variables—if necessary “hidden variables”—that are well-defined numerically.

Perhaps the most serious attack on the Copenhagen Interpretation has been led by Bohm, Vigier, and others.[12] They shared Einstein’s philosophy and endorsed his criticism of quantum mechanics. They re-affirmed the view that it is possible in principle to describe the real ontological fundamental structure and dynamics of the microscopic world. However, like Einstein, they looked for this account of the quantum system in a phase space of classically precise single-valued coordinates and momenta (the “hidden variables” of their theory). This series of papers is of a special philosophical interest as they exhibit a sophisticated awareness unusual among practicing physicists of the subtle relationship between theoretical and experimental language.

An experimental fact, for Bohm as for Einstein, is an exemplification in experience of some physical state which simply borrows its description from a theory. The theory then is logically antecedent to the recognition of the instances that fall under it. An experimental fact or datum then is a post-theoretical fact; and since, as an empirical fact, it is observable, it is an E-observable fact. Such an ‘experimental fact’ is not a B-observable fact which is a pre-theoretical fact that appears prior to and independently of special physical and conceptual constructions that the theory puts on the situation.

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[11] Quoted by Bohr in his “Discussion with Einstein on Epistemological Problems in Atomic Physics,” in *Albert Einstein: Philosopher-Scientist*, *op. cit.*, 218.

[12] For a discussion of the point of view of Bohm and Vigier, see, for example, D. Bohm, *Causality and Chance in Modern Physics* (New York: Harper, Torchbooks, 1961) where the original papers are referred to Louis de Broglie once defended this view and later returned to it: see his book, *The Current Interpretation of Wave Mechanics: A Critical Study* (Amsterdam: Elsevier, 1964). See also CDQM, 366–69, and the paper of Bell, *op. cit.* (see n. 8 above).

There are certain dogmas passionately held by many physicists that, nevertheless, are fallacious and fall under either (1) the *empiricist fallacy*, or (2) the *circularity fallacy* or *circulus vitiosus* ("vicious circle").

(i) The *empiricist fallacy* supposes that the terms of an entrenched physical theory are operationally defined to the exclusion of theoretical relations required by the postulates of the theory; these, even when entrenched, are wrongly thought merely to organize pre-theoretic or B-observable facts, with the aid of theoretical constructs.

(ii) The more sophisticated *circularity fallacy*, or *circulus vitiosus*, uses *experimental facts*—which presuppose for their description the interpretative apparatus of a theory—*as premises with which to prove the theory*. It is not my intention to discuss the epistemological relation of experimental fact to theory; few have done this better than Popper, who points out the lack of symmetry between corroboration and falsification.[13] A prediction systematically unfulfilled will disprove a theory: the same prediction systematically fulfilled does not, however, prove a theory, since in general it would not be possible to show that the theory so corroborated is uniquely capable of fulfilling an explanatory scientific role. The so-called corroborating fact, however, borrows the descriptive and interpretative apparatus of the theory it corroborates. This may involve no more than the innocuous circularity of implicit definition, the so-called *hermeneutical circle of theoretical terms*. However, if those corroborating facts were used in the course of an argument as premises from which to infer (in some strict sense of inference) the theory, then the *fallacy of a vicious circle* would be committed.

Bohm and Bub justly criticize many of the followers of the Copenhagen Interpretation, especially von Neumann, Jauch, and Piron for not being sufficiently alert to the above mentioned fallacies.[14] To employ the language of quantum mechanics (already laden with the descriptive and interpretative restrictions of the theory) in an expository context is perfectly legitimate; but great care has to be taken in the

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[13] K. Popper, *The Logic of Scientific Discovery* (London: Hutchinson, 1959) and his *Conjectures and Refutations* (London: Routledge and Kegan Paul, 1963). Lonergan's work, *Insight: A Study of Human Understanding*, *op. cit.* is also important in this regard.

[14] D. B. Bohm and J. Bub, "A Refutation of the Proof of Jauch and Piron that Hidden Variables can be Excluded from Quantum Mechanics," *Rev. Mod. Phys.*, **38** (1966): 470–75; the reference is to J. M. Jauch and C. Piron, "Can Hidden Variables be Excluded in Quantum Mechanics?" *Helv. Phys. Acta*, **36** (1963): 827–837.

justificatory context lest an argument become a vicious circle. Bohm and Bub are probably right to accuse von Neumann, Jauch, and Piron of following a vicious circle in their alleged 'proofs' that microsystems do not have classically determinate states specified by a set of hidden variables. Bohm has presented an alternative form of quantum mechanics using hidden variables, and has claimed that empirical evidence has not so far been able to falsify the new theory.

Bohm's claim of uniqueness for the 'orthodox' theory is motivated by a return to the *principle of E-observability as a reality criterion*. Later, Bohm distinguished the set of *E-observable hidden variables* from the set of *quantum mechanical observables*.[15] The quantum mechanical observables, he says, belong to the macroscopic instrument interaction with the quantum object; the *E-observable hidden variables* with their precise values describe what is really the case independently of quantum mechanical observations (measurement processes). An observation or measurement process is an 'abstraction' in the sense that it results from averaging the effects of those hidden variables which are engaged in the measurement interaction.

In 1965, J. S. Bell clarified what was intrinsically so curious about the quantum theory, and was able to set up criteria to distinguish whether hidden variables were operative in quantum physics or not. These criteria were tested experimentally by Clauser, Horne, Shimony, and Holt, and later by others, with the consequence that an entire class of hidden-variable theories were declared to be inconsistent with the experimental evidence.[16]

There have been in recent years other attempts to overcome the more restricting features of the Copenhagen Interpretation. These have centered on the logical and ontological criteria for descriptive variables that are fully defined by the mathematical form of quantum mechanics but not numerically single-valued or precise. Various terms have been used for these predicates: 'inexact predicates,' 'imprecise predicates,' etc. and the theory of such predicates has been associated with 'fuzzy sets,' 'imprecise sets' and many-valued characteristic functions.[17] Into this category

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[15] D. B. Bohm and J. Bub, "A Proposed Solution of the Measurement Problem in Quantum Mechanics by a Hidden Variables Theory," *Rev. Mod. Phys.*, **38** (1966): 453–469.

[16] J. S. Bell, "On the Einstein-Rosen-Podolsy Paradox," *Physics,* **1** (1965): 195, and J. F. Clauser, M. A. Horne, A. Shimony, and R. A. Holt, "Proposed Experiment to Test Local Hidden-Variable Theories," *Phys. Rev. Letters,* **23** (1969): 880–84.

[17] J. M. Jauch, *The Mathematical Foundations of Quantum Mechanics* (Reading, Mass.: Addison-Wesley, 1968); S. Körner, *Conceptual Thinking* (New York, Dover) and *Experience and Theory* (New York: Humanities Press, 1966); M. S. Watanabe, "The Logic of the Empirical World," *Proc. Hawaiian Conference on Philosophical Problems in Psychology,* March 1968, and *Knowing and Guessing* (New York: McGraw-Hill, 1969); M. Bunge, *Scientific Research* I (New York: Springer-Verlag, 1967), 97–162.

fall many who are experimenting with the use of non-classical sentential logic in quantum mechanics. Heisenberg in recent years has suggested that an alternative to the Copenhagen Interpretation would involve the use of a non-Aristotelian sentential logic.[18] He has supported both the pioneering work of Birkhoff and von Neumann on quantum logic and that of C. F. von Weizsäcker for whom the descriptive ontology of quantum mechanical systems is derivable from the special logic quantum mechanics appears to entail.[19]

The guiding principle of this research is the view that implicit in the present form of quantum mechanics, there are 'inexact descriptive' kinematical variables, not hidden in the sense of Einstein's or Bohm's "hidden variables," but needing, perhaps, no more than a re-formulation or a re-interpretation of the existing quantum mechanical formalism to exhibit their presence. Such a revision of quantum mechanics would remove the restriction imposed by the Copenhagen Interpretation, which limits descriptive predicates to those of classical physics.

The first step in such a program would be to articulate the logical character of a new kind of descriptive physical quantity which has the following properties: it is (1) *mathematically well-defined but is not exemplified in precise single-valued numerical instances*; (2) E-observable; (3) not necessarily B-observable; (4) exemplified in those quantum mechanical situations that are represented by a wave function (and hence prior to the specification of an observer); (5) consistent in a broad sense with the existing quantum mechanical formalism (although small changes in the formalism might be considered but not such as would require the introduction of "hidden variables"), and provides at least as good (for the systematic and predictive purposes of science) an interpretation of the formalism as does the Copenhagen Interpretation; (6) satisfies the philosophical need for a descriptive ontology of the quantum domain—that it be *objective in a realistic sense*; (7) is capable of revealing the shortcomings of the Copenhagen Interpretation while explaining the fact that it has worked successfully for so long; and (8) analogous to other and more familiar aspects of human cognitional processes, such as expressing irreducible inexactitude, or that exemplify a non-commutative character, such as in conflict of interest cases in everyday life.

Two of the most serious problems in articulating the notion of a descriptive physical quantity that is well-defined but numerically indeterminate come from the sentential logic implied by its use. The sentential logic of quantum mechanical event descriptions that are well-defined but numerically indeterminate is at odds with the classical aspects of probability theory. Before a probability measure can be

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[18] AHQP, Heisenberg-Kuhn, 27 February 1963; also PP, 181.

[19] PP, 181.

introduced, the basic sample space of states (or propositions) has to be constituted. The basic propositions will use the new numerically indeterminate predicates. In addition to the set of basic propositions, however, a sentential logic has to be assumed for the operations of conjunction, disjunction, negation, and implication involving propositions of the basic space. Since probability in a *classical sense* is a measure imposed upon a space of basic propositions, the numerical indeterminacy of the basic descriptive quantum mechanical predicates must be logically independent of the probability measure subsequently imposed on the space of quantum mechanical propositions.[20] This raises two difficult and thorny questions: first, what kind of logic is appropriate to the use of the new kind of quantum mechanical predicates? And second, how is probability to be defined (and interpreted) over such a quantum mechanical space?

With the formulation of these questions, we have probably reached the frontier of research on the epistemological and ontological structure of quantum mechanics. If quantum mechanics is to remain a respected branch of natural science, both of these questions have to be answered satisfactorily, otherwise it is possible that quantum mechanics will be replaced by a new physical theory of a less controversial philosophical character.

First question: *QM sentential logic:* To refer briefly to some positions with respect to the sentential logic of quantum mechanics, four points of view can be distinguished. Firstly, the majority of physicists, following Popper and Bunge, claim that classical general propositional logic (as formulated, say, in *Principia Mathematica*) is sufficient for quantum mechanics.[21] Secondly, there is the claim made by Birkhoff and von Neumann,[22] and later taken up by Jauch, Mackey, Finkelstein, Mittelstaedt, Ludwig, Scheibe, Watanabe and others,[23] that the

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[20] See Popper's appropriate remarks in his essay "Quantum Mechanics Without 'The Observer'," in *Quantum Theory and Reality*, ed. by M. Bunge (New York: Springer-Verlag, 1967), 7–44, especially 19.

[21] M. Bunge, "A Ghost-Free Axiomatization of Quantum Mechanics," in *Quantum Theory and Reality*, ed. M. Bunge, *op. cit.*, 105–17; K. Popper, "Quantum Mechanics without 'The Observer'," *ibid.*, 7–44.

[22] G. Birkhoff and J. von Neumann, "The Logic of Quantum Mechanics," *Ann. Math.*, **37** (1961): 155–84.

[23] G. Mackey, *The Mathematical Foundations of Quantum Mechanics* (New York: Benjamin, 1963); J. M. Jauch, *The Mathematical Foundations of Quantum Mechanics, op. cit.*; D. Finkelstein, "Matter, space and logic," *Boston Studies in the Philosophy of Science,* 5, ed. by R. S. Cohen and M. Wartofsky (New York: Humanities Press, 1969), 199–215; P. Mittelstaedt, *Philosophische Probleme der modernen Physik* (Mannheim: *Bibliographisches Institut*, 1966); M. S. Watanabe, "Algebra of observation.," *Progress of Theor. Phys., Suppl.* (1965): 305–67; G. Ludwig, "An Axiomatic Foundation of Quantum Mechanics on a Nonsubjective Basis,"

empirical descriptive sentences of quantum mechanics constitute a space of basic propositions subject to a logic similar to classical general propositional logic but one lacking the distributive laws between "and" and "or." Thirdly, there is the view of Reichenbach, C. F. von Weizsäcker, Destouches-Février and Suppes[24] that quantum mechanics needs (*indeterminate) truth values intermediate between truth and falsity*. Fourthly, there is the present author's view that there are necessarily two descriptive languages in quantum mechanics, a *QM event-language* and its *QM contextual language*[25]*;* the latter describes the *a priori* context in which the QM event occurs and that necessarily conditions the description.[26] The QM contextual (or horizonal) language uses a non-distributive lattice logic; QM event language, though restricted to context-dependent domains, is not subject in its internal logic to this restriction and it seems likely that classical logic is adequate for its needs. Bunge[27], who also stresses the context-dependent (or horizonal) character of quantum mechanical variables, declares in favor of classical logic.

Second question: *QM Probability Measures:* There are in general three points of view regarding the notion of probability. *First*, there is the claim of Suppes, Varadarajan, Margenau, and others,[28] that the classical (Kolmogoroff) axioms of

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in *Quantum Theory and Reality*, ed. by M. Bunge, *op. cit*., 98–104; E. Scheibe, *Die kontingenten Aussagen in der Physik* (Frankfurt: Athenäum, 1964).

[24] H. Reichenbach, *Philosophic Foundations of Quantum Mechanics* (Berkeley: Univ. of California Press, 1944); P. Suppes, "Measurement, Empirical Meaningfulness and Three-valued Logic" in *Measurement: Definitions and Theories*, ed. by C. West Churchman and P. Ratoosh (New York: John Wiley, 1959), 129–43; C. F. von Weizsäcker, "*Komplementarität und Logik*," *Naturw*., **42** (1955): 521–29, "*Die Quantentheorie der einfachen Alternative*," *Zeitschr. f. Naturforsch*., **13a** (1958): 247–53; C. F. von Weizsäcker, E. Scheibe and G. Süssmann, "*Komplementarität und Logik: III Mehrfache Quantelung*," *Zeitschr. f. Natur-forsch*., **13a** (1958): 705–21; P. Destouches-Février, *La structure des theories physiques* (Paris: Presses Universitaires, 1951).

[25] Alternatively called QM horizonal language where 'horizon' is physical as well as cultural while 'contextual' tends to be just cultural.

[26] P. A. Heelan, "Quantum Logic and Classical Logic: Their Respective Roles," *Synthese* **22** (1970): 3–33 and in *Logical and Epistemological Studies in Contemporary Physics,* ed. by R. S. Cohen and M. Wartofsky. *Boston Studies in the Philosophy of Science Series,* **13** (The Hague: Reidel, 1974), 318–349.

[27] M. Bunge, "A Ghost-Free Axiomatization of Quantum Mechanics" in *Quantum Theory and Reality*, ed. by M. Bunge, *op. cit.*

[28] H. Margenau, "Measurement and Quantum States," *Philos. Sci.*, **30** (1963): 1–16, 138–57; H. Margenau and L. Cohen, "Probabilities in Quantum Mechanics," in *Quantum Mechanics and Reality,* ed. by M. Bunge, *op. cit.*, 71–89; P. Suppes, "Probability Concepts in Quantum Mechanics," *Philos. Sci.*, **28** (1961): 378–89; "The Probabilistic Argument for a Non-Classical Logic in Quantum Mechanics," *Philos. Sci.*, **33** (1966): 14–21; V. S. Varadarajan, "Probability

the probability calculus do not apply to quantum mechanics since, for example, there is no joint probability for a set of non-commuting variables in quantum mechanics. *Secondly*, there is the claim of Popper, Bunge, and others,[29] that quantum mechanics uses no more than a classical conditional probability, and that leads Popper to his propensity interpretation of probability in quantum mechanics. *Thirdly*, there is the point of view suggested by Shimony, that the notion of probability used in quantum mechanics, which is usually taken in one or other of its objective senses, might well be interpreted in the sense of *subjective probability*.

I shall not enter further into these controversial matters. The aim in this book is just to articulate the critical epistemological problems implicated in the historical development of quantum mechanics.

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in Physics and a Theorem on Simultaneous Observability," *Comm. Pure Appl. Math.*, **15** (1968): 189–217 and his *Geometry of the Quantum Theory* (Princeton: D. Van Nostrand, 1968).

[29] K. Popper, "The Propensity Interpretation of the Calculus of Probability and the Quantum Theory," in *Observation and Interpretation in the Philosophy of Physics*, ed. by S. Körner (New York, Dover: 1962), 65–70; M. Bunge, "A Ghost-Free Axiomatization of Quantum Mechanics," *op. cit*.

CHAPTER FIFTEEN

Objectivity and Realism in Quantum Mechanics

The problem of objectivity and realism in quantum mechanics can be stated now more clearly.[1] Let us suppose that 'objectivity' is that property of a description that warrants the acceptance as 'real' of what is described as so described. Then, there are three problem areas to be investigated: (1) a strictly philosophical one which attempts to articulate critically the kind of objectivity that characterizes a realistic statement; (2) then having agreed on acceptable criteria of objectivity, the next step is to investigate how these apply or should be applied to quantum mechanics so as to elucidate the objective structure of the realities so described; 3) finally, one has to account for claims of the kind that seem to inject psychology into the heart of physics.

1) I shall not enter deeply into the strictly philosophical problem of objectivity, since I have treated it elsewhere[2] and, moreover, an excellent study of the problem

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[1] Many physicists and philosophers have concerned themselves with the central problem of what constitutes the kind of objectivity compatible with scientific claims, for example, E. Wigner, *Symmetries and Reflections*, *op. cit.*, B. D'Espagnat, *Conceptions de la physique contemporaine* (Paris: Hermann, 1965), H. Margenau and J. L. Park, "Objectivity in Quantum Mechanics" in *Delaware Seminar on the Foundations of Physics,* ed. by M. Bunge, *op. cit.*, 161–87.

[2] P. A. Heelan, *Quantum Mechanics and Objectivity*, *op. cit.*, and "Horizon, Objectivity and Reality in the Physical Sciences," *Internat. Philos. Qrtly*, 7 (1967): 375–412.

of objectivity in science exists in Bernard Lonergan's *Insight, A Study of Human Understanding*.[3] The problem requires that different kinds of objectivity be distinguished: (a) Heisenberg's "objectifiability," which is linked with the Newtonian picture of the world and with the principle of B-observability; (b) the public (socio-historical) objectivity of publicly testable claims; and (c) the strict objectivity of empirically warranted factual descriptions formulated within an accepted descriptive framework where all the descriptive predicates satisfy the principle of E-observability.

The Copenhagen choice of (a) was eventually endorsed by Heisenberg. According to this criterion, no situation could be called 'real' or 'objective' that did not have an objectifiable description. But since every QM event is a function of the environment with which the quantum mechanical system interacts; and since its environment is—in the accepted terminology of quantum mechanics,[4] the 'observer'—no objectifiable description is possible. This would not have caused any difficulty had objectifiability not been chosen as the criterion of reality, for the twofold restriction it imposes, namely, that the observer (as a physical agent) cannot be active in the production of the QM event, and that the observer (as a knower) cannot be active in constituting the descriptive categories under which the description of the quantum mechanical event is formulated, makes an objectifiable description of a quantum mechanical event impossible. Epistemologically more satisfactory is the criterion of public and strict objectivity, and most contemporary critics of the Copenhagen Interpretation, like Popper, Bunge, Bub[5]—with the possible exception of some "hidden variables" theorists—have at least implicitly adopted this view.

2) Supposing that public and strict objectivity are the criteria of reality, what then is the objective structure of the quantum mechanical object? A QM object reveals itself as a function of a measuring environment. What constitutes a particular environment to be a measuring environment is that it can be used as a communication

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[3] B. F. Lonergan, *Insight: A Study of Human Understanding* (London: Longmans, 1957).

[4] In the accepted terminology, the QM observer is the physical environment which includes both the measuring instrument as the signaling medium and the observer as the human interpreter of the message communicated by the medium.

[5] K. Popper, "The Propensity Interpretation of Probability," *Brit. Jour. Phil. Sci.*, **10** (1959): 25–42, "Quantum mechanics without 'The Observer'," in *Quantum Theory and Reality*, ed. by M. Bunge, 7–44; M. Bunge, "Strife about Complementarity," *Brit. Jour. Phil. Sci.*, **6** (1955): 1–12, 141–54, "A Ghost-Free Axiomatization of Quantum Mechanics," *ibid.*, 98–117; J. Bub, "Hidden Variables and the Copenhagen Interpretation," *Brit. Jour. Phil. Sci.*, **19** (1968): 185–210.

channel between an object and an observing scientist. The communication takes place through signals produced in the measuring environment by the QM object. The scientist, who has learnt to interpret these signals in the light of the quantum theory, can then 'read' in them the description of the QM event taking place. This view, as I have tried to show, is implicit in Heisenberg's writings.[6]

A quantum mechanical event-description is then a context-dependent description. The measurement context that defines the QM event entails dependence on a type of environmental invariance that is not compatible with the classical invariance of space-time.

The quantum event is the outcome of an interaction with the measuring environment and the descriptive predicates entailed by this are incompatible with the precise numerical values characteristic of a classical environment. The formal logical use of such 'imprecise' predicates is still not clear—are they classical or non-classical? Two-valued or many-valued? Nor is it clear how probability measures on such predicates should to be defined—objectively or subjectively? Classically or non-classically?

3) The language of the Copenhagen School, and especially of Heisenberg, has been vigorously criticized because of its tendency to psychologize physics.[7] Many critics find such phrases as "the traditional requirement of science … [such as] a division of the world into subject and object (observer and observed) is not permissible in atomic physics,"[8] and "quantum mechanical formulae no longer describe nature but our knowledge of nature,"[9] as repugnant to the scientific tradition and as contributing to a confusion between psychology and physics. Popper, for example, wants "to exorcise the ghost called 'consciousness' or 'observer' from quantum mechanics, and to show that quantum mechanics is as 'objective' a theory as, say, classical statistical mechanics."[10] Bunge writes "Theoretical physics must be kept thoroughly physical, strictly ghost free, or else its name must be changed to 'psychology'."[11] The principal ghost is, of course, the observer.[12]

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[6] Cf. chap. XI.

[7] The critics of the Copenhagen Interpretation comprise among others: Bohm, Bopp, Bunge, Einstein, Feyerabend, Landé, Ludwig, Margenau, and Popper. See bibliography for references.

[8] PPQT, 2.

[9] PCN, 25.

[10] Popper in *Quantum Mechanics and Reality*, ed. by M. Bunge, *op. cit.*, 7.

[11] Bunge, *ibid.* 107.

[12] Bunge writes: "The usual interpretation of quantum mechanics—and also of relativistic theories—teems with the ghostly: the theoreticians demand that every symbol, even if it

Neither Popper nor Bunge would deny the existence and legitimate role of subjects, observers, and consciousness in creating, interpreting, and using physics. They want, however, to remove mental or psychological terms from among the descriptive terms of physics. "The concern of physics is not the observer and what he feels and thinks, but the physical object."[13]

The term *observer in classical physics* connotes a '*disembodied observer*'; 'disembodied' in this context means that the observer in 'observing' contributes nothing to the act of measurement other than the recognition expressed in mental and linguistic terms of the objective outcome of the measurement process; 'observing' then has no effect on the object measured or on the measuring apparatus. 'Observation' under such conditions is considered to be *purely psychological*.

The *observer in quantum physics* is an '*embodied observer*' who acts as both a *psychological* and a *physical agent; the term 'QM observer'* connotes the special role that the physical context of the measurement process plays in determining the outcome of the QM measurement event. The QM observer then is a physical as well as a mental participant on the 'observer side' of the measurement process. It is within such a context that the QM object interacts and a physical signal is produced that is interpreted mentally and linguistically by the QM observer. *The physical signal—as the sign-fact—is described in* L_O *or* L_N*; the QM event—as the signified fact—is described in* L_Q. Only the psychological observer, 'reading and interpreting' the instrumental signs, can know the signified fact, which is a fact described, not in L_O or L_N, but in some not yet adequately researched QM descriptive language L_Q.

This conclusion is contrary to what Heisenberg seems at times to say—that the sign-fact 'is'—or can be 'read' by the 'observer' as—the QM event. Such ambiguity in the meaning of the term 'observer' appears, for example, in the context of Heisenberg's claim that "the traditional requirement of science [is] a division of the world into subject and object (observer and observed),"[14] Every division of a process, say, into two distinct parts requires a principle of division; here, between subject and object, between observer from observed. Part of the confusion between psychology and physics is caused by the fact that there are two different principles of division leading to two different kinds of subject/object and observer/observed

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performs a purely computation function, be correlated to an experimental item; the observer's decision to look or not to look at the meter as decisive for the state of the object; the ideal measurement which nobody will ever perform; the 'observables' which nobody can perceive; the interpretation of averages as expectation values and scatters as uncertainties. All these are ghosts in the sense that they are not physical items. Most of them are in fact psychological ideas." *Quantum Theory and Reality*, 105–6.

[13] Bunge, *ibid.*, 107.

[14] PPQT, 2.

‘cuts,’ which, when used concurrently, and not adequately distinguished, lead to confusion.

One principle of division is spatial: it makes spatial ‘cuts’ which divide physical space into two parts, one which is ‘internal (spatially)’ to the subject and the other which is ‘external (spatially)’ to the subject. This is easily confused with an analogous division in the ‘space’ of ‘subject/object intentionality of meaning-making’ (see below). The spatial division places a material or physical cut between the ‘embodied subject’ and the ‘embodied object.’ According to this principle, the ‘subject’ is ‘internally’ embodied in this spatial world, while the ‘object’ is ‘externally’ embodied in the same world. But such a division leaves on both sides of the ‘cut’ spatio-temporal objects exemplifying the same set of physical predicates. The subject in this division is just another part, albeit an ‘internal’ part, of the physical world: it is not—in terms of this division at least—a knower.

The second principle of division is subject/object intentionality of meaning-making;[15] this is the making of *noetic-noematic* ‘cuts’ (within the ‘space’ of cognitive awareness). This divides the ‘space’ of cognitive awareness of the world by a ‘cut’ that distinguishes the *noetic*-subject (knower) from the *noematic*-object (known); the distinction is within the notion of ‘being’ or ‘reality.’ According to this division, the known object is not separated from the subject in any physical or spatial sense—both subject and object are ‘within the *intentional space* of human consciousness’ and it is within this intentional space that the ‘cut’ between subject and object is made. Such a distinction is not described in physical or spatial terms, but in phenomenological and epistemological terms. The known as such is logically and phenomenologically distinct from the knower as such, but the physical known is not necessarily physically distinct from the physical knower.

Now the usual treatment of the observer-observed cut in physics does not bring out clearly that two incommensurable principles of division are involved—a physical cut with a physical description and a noetic cut with a phenomenological/epistemological description. However, while keeping in mind the danger of confusing the two cuts, I think it is in keeping with the spirit of Heisenberg’s insight into the role of the measuring instrument in quantum mechanics to take the observer-observed cut to be simultaneously both physical and noetic, leaving

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[15] The notion of intentionality belongs to the phenomenological and hermeneutical tradition of Husserl, Heidegger, Merleau-Ponty, Gadamer, and others, and is about how we make meanings that intend ‘being’ or ‘reality.’ All descriptive languages are rooted in ways of making meaning about the world people live in.

on the subject side of the cut a Mind embodied in the measurement process, and on the object side a physical object shaped by the cognitive intentions of such a Mind. I trust that this usage of mine will work and not lead to further confusion. My justification is that throughout this study, it was not my purpose to correct Heisenberg's view, but to present it as coherently as possible using as much of his own language as could be used without perpetrating confusions of the kind discussed in this chapter.

Moreover, there is a precedent for including the measuring environment as a defining part of 'the observer.' This is so, for instance, in relativity where the physical space-time frame is called 'the observer's frame' or simply 'the observer.' Moreover, the analysis given in chapter XI makes the point that a scientist 'reads' instruments as one reads linguistic signs by a kind of non-inferential cognitive activity similar in epistemological structure to the way one uses one's sensory organs. Consequently, there is a firm analogy between the way one perceives through one's senses, and the way one 'perceives' through the expert use of instruments. This should not obscure the fact, however, that in order to 'perceive' through the use of an instrument, the physical structure of the object/instrument interaction has first to be understood, and this understanding is precisely what science gives.

The claim that "quantum mechanical formulas no longer describe nature but our knowledge of nature"[16] summarizes all the philosophical perplexities that quantum mechanics has produced. A QM formula (e.g., the wave function) does not describe an objectifiable reality: the wave function has first to be transformed into a mixture by specifying an observer, and then the mixture is sampled by an observation. The specification of the observer is given in (what I have called) the QM meta-context language. This includes the description of the measuring environment and names the QM event language appropriate for the use of this observer. In the Copenhagen Interpretation, the only descriptive languages are L_O and L_N, and the scientist has to learn the logic of complementarity which tells the scientist when to use one set of descriptive predicates and when to use another set. The Copenhagen Interpretation teaches one how to make (metaphorical?) use of the objectifiable meanings of classical physics within the context of quantum physics.

The root cause of these difficulties is the criterion of objectifiability and the confusion it tends to produce between the physical and the epistemological aspects of an observer who is embodied in a measurement process. I have proposed that

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[16] PCN, 25.

this criterion be dropped in favor of the more flexible one of public and strict objectivity. This proposal would involve replacing the principle of B-observability by the principle of E-observability. Taking into account the long and respected history which the latter principle has had both in science and in philosophy, the proposal, moreover, appears neither revolutionary nor implausible.

CHAPTER SIXTEEN

Observation, Description, and Ontology: Summary

I have studied a set of philosophical problems central to the understanding of the historical development of quantum mechanics, centered on the reflections of Werner Heisenberg. Why Heisenberg? Because, from an early age, he was well-read both in philosophy and in mathematics, and did in fact express in words his thoughtful reflections on quantum mechanics as they moved through the early critical stages of philosophical critiques by his more senior colleagues. Among these were Einstein, Schrödinger, Bohr, Pauli, Born, Wigner, von Neumann, Rosenfeld, Wheeler—to mention just a few. Since textbook accounts of quantum mechanics generally suppose either the irrelevance of philosophical issues to natural science or mention them only to obscure and often only to trivialize them, I have focused my study on the work of one star young physicist, Werner Heisenberg [1901–†1976]. He is both the architect of quantum mechanics and a colleague of prominent European philosophers, such as M. Heidegger and C. F. von Weizsäcker.[1] Heisenberg is the author

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[1] Heisenberg's relations with American and British philosophers of science were marred both by the false impression that Heisenberg collaborated dishonorably with the Hitler regime and by the fact that their philosophical interests were far apart. Heisenberg saw science as a part of philosophy and needing the authority of the ancient philosophical tradition rooted in Greek philosophy, while his trans-Atlantic colleagues saw science more as a socio-cultural tool subordinated to the demands of scientific and technological expansion.

of many probing philosophically sophisticated essays about quantum mechanics that should be read with the mind of one who is both a creative scientist but also one who tells us about ourselves and the world we live in.

I also had the privilege of working closely with him while doing research on the philosophy of science while I was associated with the Edmund Husserl Archives at the University of Leuven in Belgium in 1962–64.

This study is dominated by the three themes that recur contrapuntally in Heisenberg's writings: *observation*, *description*, and *ontology*—always with a concern about the role played by the subjective inquirer in scientific meaning-making and the ontology of scientific claims. Among the related themes are; *the tension between paradigmatic concerns with structure* and *philosophical concerns with reality*, *the possibility of scientific revolutions, such as relativity and quantum mechanics, that overthrow the classical traditions of natural science*, and the *inadequacy of a psychophysical parallelism for an epistemology of reason*. The influence of Husserl and Heidegger is in his concern about the role of subjectivity. Heisenberg was a long-time friend of Heidegger in whose honor he contributed an essay to his *Festschrift* in 1959. He was then familiar with Heidegger's hermeneutical phenomenology and its critique of Greek philosophy.

I have muted the contribution of phenomenology to Heisenberg's philosophy of science because it is of little interest to my American and British readers whose objective interest tends to be disconnected from the study of the hermeneutical meaning-making processes and are concerned more with the correct use of language. The strangeness of both relativity and quantum physics needs to be made explicit in a variety of ways—linguistic and hermeneutical—so that its origins can be better understood.

I shall recapitulate below the results of this study in a set of ten propositions. Some of the propositions refer to topics explicitly raised by Heisenberg himself and others refer to debates on quantum mechanics that arose immediately after the publication of Heisenberg's 1925 paper and continue to be discussed today.

The ten propositions are the following:

I. For Heisenberg, physical science is the search for and tentative expression of an *ontology of nature*.

II. For Heisenberg, the appropriate criterion for an ontology of nature is *observability*; but it has two forms, a *rationalist* form, *E-observability* (where "E" stands for "Einstein" for whom the *ontology* was defined by the *classical ideal of a mathematical theory*) and an *empiricist* form, *B-observability* ("B" stands for "Bohr" for whom ontology was defined by *classical localization in space and time*).

III. In the historical development of QM, a *scientific revolution* originally proposed by Heisenberg was blocked by the conservative empiricist epistemology of Bohr; and the tension between two viewpoints was temporarily resolved by the *invention of a new linguistic paradigm,* "*complementarity.*"

IV. The *new paradigm* was driven by the tension between the two initial irreconcilable sets of philosophical values.

V. *Complementarity* was a new *paradigmatic way of thinking and speaking* about QM objects that used *only the classical language of particles and fields.*

VI. The *QM- observer and the QM-observed* are correlative 1): there are as many *QM descriptive quantum-event-languages as there are* appropriate standard laboratory setups to measure the finite sets of non-congruent descriptions that the language permits to be enacted; 2) the situation just described is not describable in a descriptive quantum-event-language but only by reflecting on the fact of such a plurality as arising from the multiple choices a QM-observer can make in creating and unveiling the non-congruent sets of QM-objects that follow from the nature of QM. Reflecting on this situation as such, one moves beyond all *QM descriptive quantum-event-languages* onto a higher order language, a *QM-meta-context-language* that speaks from a new self-awareness of an agent in the world—influenced by notions of choice and guided by love, beauty, joy or their opposites and which pertain not to any object of inquiry but to the active subject and his/her disposition towards human life.

VII. The principal competing types of *QM descriptive languages* which enter into the history of quantum mechanics are the following: L_A (**A**ristotelian language), L_O (contemporary **O**rdinary language), L_N (**N**ewtonian language), L_R (**R**elativistic language), L_Q (**Q**uantum mechanical language); and, in addition, L_P (**P**re-theoretical language) and L_T, (**T**heoretical language).

VIII. The *measuring apparatus plays an information-theoretic role* in a QM observation, analogous to a physical extension of the physical sensory organs.

IX. *Psychophysical parallelism*, as inherited from classical psychology, is *inadequate for objectivity, nor does it resolve the philosophical problems that arise in quantum mechanics.*

X. Since the root cause for introducing psychology into the heart of quantum physics is the principle of B-observability, the move to psychology needs to be replaced by the phenomenological notions of 'intentionality' and 'hermeneutics' central to the philosophy of Husserl, Heidegger, Merleau-Ponty, and Gadamer. The criterion of B-observability should therefore be dropped in favor of *Heisenberg's and Einstein's original Principle of E-observability* but one that accepts the *Unanschaulichkeit* of the QM object.

I. *In Heisenberg's view, physical science is the tentative expression of and search for an ontology of nature.*

For Heisenberg, the objective of a scientific account was to describe what physical reality is really like. Its goal was to give an ontological account of nature, taking 'ontology' to mean what others call 'metaphysics'—namely, the science of what is independently of human culture and history—although he recognized that this might not be possible in the micro-domain.[2] Having begun in his first paper with the intention of revolutionizing the descriptive ontology of QM systems as Einstein revolutionized space and time,[3] he later moderated his goal under Bohr's influence to that of building a scientific paradigm, namely, *complementarity,* whose principal purpose was to promote *communication* in quantum theoretical research using the resources of the language of classical physics.[4] Much later, he found expression for his basic ontological interest in physics by adopting the Aristotelian notion of *potentia*, which, as he proposed, described the kind of reality represented by the QM wave function.[5]

II. *The ontological criterion is observability; it has two forms, a more rationalist form E-observability ("E" stands for "Einstein") and a more empiricist form B-observability ("B" stands for "Bohr").*

Under the influence of what he understood Einstein to have done, Heisenberg adopted in his first paper the criterion that *only observables* should enter into quantum mechanics, since only observables were warranted as ontological, i.e., real.[6] Heisenberg's original notion of observability (namely, E-observability) admitted as observable states only states that were not precisely localized, e.g., stationary states. Bohr took the view that the ontological criterion was localizability in L_N

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[2] Chaps. I, III, VII.

[3] Chaps. II, III.

[4] Chaps. V, VII.

[5] Chap. XIII.

[6] Chaps. I, II, III.

(classical Newtonian language), the sense I call 'B-observability.' Heisenberg came to accept this latter view.[7] Much later, Heisenberg found that E-observability could play an ontological role in pointing to the existence of (what the Latin medieval authors called) a *potentia* (in German, *Potentialität,* or in English, a *potency*). A fulfilled *potentia* becomes an a*ctualitas* (in German, *Aktualität,* or in English, an *actuality, actual object,* or *event*)—a *reality in the existential sense* characterized by B-observability.[8]

III. *In the historical development of quantum mechanics (QM), a scientific revolution originally proposed by Heisenberg was blocked by the conservative empiricist epistemology of Bohr.*

Heisenberg's adoption of B-observability as the sole criterion of reality blocked his initial impulse to revolutionize the descriptive ontology of QM systems, for the new kinematical concepts he proposed in his first paper were not B-observable and consequently did not fulfill the new criterion. Bohr did not believe in the possibility of revolutions in descriptive ontology.[9]

IV. *The tension between two irreconcilable sets of philosophical values can be resolved by the invention of a new paradigm.*

The tension between Heisenberg's predominantly ontological interest and Bohr's more conservative interest in communicability using existing linguistic resources led to Heisenberg's adoption of *complementarity*. Complementarity was a way of thinking and speaking about quantum theoretical objects using classical language.[10] Although successful, complementarity for Heisenberg did not fulfill the ultimate goal of a physical science. He came to believe as a consequence that classical physics expressed the limit of what the scientist could know descriptively about nature and that quantum physics spoke at most of the disposition of microscopic systems to produce macroscopic effects in observers.[11] Heisenberg retained his belief that revolutions in descriptive ontology could take place and much later held that only the old linguistic conventions prevented the accomplishment of a revolution of this kind.[12] Bohr would not have endorsed this view.

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[7] Chaps. II, VII. VIII, X.

[8] Chap. XIII.

[9] Chaps. VIII, IX.

[10] Chap. VIII.

[11] Chap. IX.

[12] Chap. XIII, XIV.

V. *In the practice of quantum mechanics, complementarity is a new paradigmatic way of thinking and speaking about QM objects using classical language.*

Complementarity is a higher logic that regulates the use of classical physical concepts to describe quantum mechanical systems. Complementarity forbids the simul-taneous use of two conjugate classical concepts, like position (a localized particle event description resulting from an interaction with its environment) and momentum (a non-localized wave description closed to interaction with its environment). The rationale of complementarity is communicability using the resources of ordinary language and the language of classical physics. It refuses to answer questions about descriptive ontology.[13]

VI. *The correlative character of observer and observed implies 1) that there are many descriptive QM event languages, each one sketches out a domain of objective realistic knowledge of which the knower subject is also an embodied Mind; the QM Mind is embodied in the laboratory setup and measuring process; 2) that the laboratory setup and the measuring process is described from the point of view of a laboratory engineer using a QM meta-context language.*

In quantum mechanics, Heisenberg affirms that every QM object-event is an object-event-for-a-particular-kind-of-QM-observer; and every QM observer is related to a manifold of object-events.[14] An observed QM object-event is described by a descriptive statement that itself supposes the existence of the resources of a QM descriptive language. The QM descriptive language is the possession of the QM observer and expresses the manifold possibility of the observer's experience. In quantum mechanics, the observer is the human subject linked with whatever external apparatus is chosen for the purposes of a QM measurement.[15] QM observers are many and they are not all mutually compatible, since external instrumentation of one kind (e.g., for localization) cannot appropriately be used simultaneously with external instrumentation of another kind (e.g., to measure momentum). To the manifold of QM observers, there corresponds a manifold of QM descriptive languages which cannot all be used simultaneously.[16] The observer and the observed are separated by a theoretical *cut* which is movable subject to

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[13] Chap. VIII.

[14] Chaps. VI, IX, X, XI, XIII, XIV.

[15] Chaps. X, XI, XV.

[16] Chaps. VI, IX, X.

a decision of the scientist.[17] Besides the manifold of QM descriptive event languages, there is a language (the QM meta-context language) that describes the observer-observed relation from a standpoint invariant with respect to the position of the *cut*. This standpoint plays the role of *The Universal Inertial Observer* in special relativity or *The Absolute Observer* in general relativity.[18]

VII. *The principal competing QM descriptive languages entering into the history of quantum mechanics are* L_A *(Aristotelian language),* L_O *(contemporary ordinary language),* L_N *(Newtonian language),* L_R *(relativistic language),* L_Q *(quantum mechanical language); in addition* L_P *(pre-theoretical language) and* L_T*, (theoretical language) are correlative language types rather than languages.*

We have a choice among many different descriptive languages: L_A, an 'Aristotelian' language that distinguishes objects through the use of predicates that unite the object directly with the perceptual experience or purposive activity of the human subject;[19] L_N, the mathematical physical language of classical physics, based principally upon the measurement of primary quantities;[20] L_R, the mathematical physical language of relativistic physics;[21] L_O, the ordinary language of our epoch which is a sedimentation of L_A, L_N and perhaps a little L_R;[22] L_Q, the language used of the QM object,[23] and L_P, which is any language used to specify a problem area *before* the problem area is *explained* by an appropriate theory T. If L_T is the new theoretical language and L_P is the pre-theoretical-language, then L_P is prior to L_T—not, however, prior to all theory but prior only to the related L_P.[24] The principal contrapuntal theme is the tension between conventionally sanctioned language (language in *de facto* use) and philosophically sanctioned language (language as it should be used if philosophical values are to be best fulfilled). Consequently, there is a tension between L_A and L_N, L_N and L_R, L_N and L_Q and in fact between any L_P and the correlative L_T. Einstein and Heisenberg endorsed the principle that it is the theoretical language which carries the ontology. Hence L_A should be replaced by L_N, L_N should be replaced by L_R, and, in general, any L_P should be replaced

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[17] Chaps. X, XV.

[18] Chaps. I, II, XI.

[19] Chap. II.

[20] Chap. II.

[21] Chap. II.

[22] Chaps. VII, VIII, XI.

[23] Chap. III.

[24] Chap. II.

by its corresponding L_T.[25] However, since *in the complementarity interpretation*, L_Q contains no descriptive predicate that is not already in L_N, consequently, L_Q does not add anything to the ontological description of physical systems, nor does it replace L_N as a descriptive language.[26]

VIII. *The measuring apparatus plays an information-theoretic role in a QM observation, analogous of an extension of the sensory organs.*

In quantum mechanics, the instrument as such is part of the QM observer. Since observation is a non-inferential act endorsing the reality of what is observed and described, the instrumental response plays the role, not of a premise, but of a linguistic sign, like a sentence as if 'spoken' by the instrument to 'describe' the QM object.[27] The objective meaning of this sign for the scientific community comes from the physical theory that describes the relation between the object and the instrument. In the case of quantum mechanics, the object modulates the signal channels of the instrument. Thus, on the one hand, it is not necessary that one and the same language be appropriate for the description of the sign-fact (signal) and signified-fact (QM event-object).[28] On the other hand, *complementarity* restricts the scientist's linguistic resources for descriptive expression exclusively to the language appropriate to the description of sign-facts;[29] that is, only L_O and L_N are admitted as truly descriptive. The manner in which an instrument channels information to a human subject immediately and non-inferentially makes it the analogue of a human sensory organ.[30] The instrument then permits a scientist to observe what otherwise would be imperceptible.

IX. *Psychophysical parallelism, inherited from classical psychology, is inadequate for objectivity, neither does it resolve the philosophical problems in quantum mechanics.*

In the thinking of both Heisenberg and Bohr, the type of objective knowledge that truly describes what is the case is identified with knowledge of objectifiable objects and is linked with a parallelistic epistemology; they adhere to the view that the subject to know should not contribute to the physical production of its object or to

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[25] Chaps. II, III, VII.

[26] Chaps. VIII, XII.

[27] Chap. XI.

[28] Chap. XI.

[29] Chaps. VIII, XII, XIV.

[30] Chap. XI.

the descriptive categories used to describe the object.[31] But with respect to the QM object, the subject is in fact involved in both the production of its object (since the object manifests itself only as a function of the measurement interaction with its environment) and in the constitution of the descriptive categories which implicate the observer in the set of relationships they intend to describe.[32] An objectifiable object is one that is represented as prior to and independent of any relation to a knower-subject. This seems to be too stringent a demand to impose on all that is claimed to be objective and scientific knowledge, sufficient for truth (even in the sense of conformity) that what is asserted is claimed to be independent of its being asserted by this or any other knower-subject, even though what is asserted may at times involve the subject both physically (in the production of the event-object) and intentionally (in the construction of the meanings used in the event-description). This is the kind of truth that quantum mechanics reaches. It is, moreover, both objective, at least in the sense of being public, and it is scientific, at least in the sense of being systematic knowledge warranted by public and reproducible empirical evidence. It is not, however, what Heisenberg would call 'objectifiable' truth. Perhaps, it is sufficient for scientific knowledge that it be a body of systematic empirically warranted and objective truth, even if its object, paradoxically, includes the scientist in some respect, such as what is implied in QM measurement.[33]

X. *The root cause for introducing psychology into the heart of quantum physics is the principle of B-observability. The criterion of B-observability should therefore be dropped in favor of Heisenberg's—and Einstein's—original Principle of E-observability.*

The language of the Copenhagen School has been vigorously criticized because of its tendency to psychologize physics, making the value, and even the existence, of physical quantities depend on their being observed by an observer. Two different principles of division are involved in distinguishing the observer from the observed—a *noetic principle* (in the field of cognitive awareness) and a *spatial or physical principle* (in the order of physical description). These two accounts of what constitutes the QM observer have resulted in confusion that is the root cause of psychological terms being introduced into physical descriptions. Quantum mechanics, however, has been responsible for an important insight, that the correlative of the object of a QM description is not a disembodied Mind, such as the classical observer, but an embodied Mind. Consequently I have proposed that the

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[31] Chaps. I, V, IX.

[32] Chaps. IX, X, XI, XIV.

[33] Chaps. I, XV.

classical principle of objectifiability be replaced as an ontological criterion by the more flexible one of public and strict objectivity of warranted empirical facts. *This proposal would result in the replacement of the Principle of B-observability by (Heisenberg's original) Principle of E-observability.*[34]

This study has also raised some important questions concerning *conventionality* and *development*.

Conventionality is a property associated with the general language framework of a community, but nevertheless is not univocal with the variety of different cultural sub-communities within the general community that nevertheless express valid but incommensurable 'local' forms of social experience. Conventionality is generally associated with the common ordinary language of the general community (L_O); nevertheless there are political, cultural, scientific sub-communities within it that use particular 'local' frames generally incommensurable among themselves and incommensurable also with L_O but nevertheless are valid in everyday use that is strictly 'local.'[35]

The example I have used for this is *space as classically measured* and *space as measured by binocular visual constructions*. While ordinary language incorporates L_N as its norm, artists, such as Van Gogh and Cezanne, seem to have used binocular visual criteria, judging by the way pictorial space has been portrayed in their paintings.[36] To move from one descriptive frame to another and to return back as one's community's interests should not in principle be impossible—given appropriate contextual cues as to which language is being used at any time. However, as the vehicle for expressing ontology, one frame has to be preferred as the frame of the real on philosophical or traditional or other grounds. Other frames then would, perhaps, be held to describe just phenomena or appearances—but not the 'real.' We have seen that in the case of Einstein and Heisenberg, the philosophical principle governing the choice of an ontological language was that the (mathematical) theoretical framework be descriptive of reality; while the pre-theoretical frameworks are taken to belong just to phenomena or the appearances of reality.[37]

My own position is that pre-theoretical frameworks and theoretical languages also reach horizons of real facts, but facts differently constituted—in the former case as things-to-subjects-for-subjects, in the latter case as things-to-(subjects-embodied-in-instruments)-for-such-subjects.[38]

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[34] Chap. XV.

[35] Chaps. XI, XIII.

[36] Chap. XI.

[37] Chaps. II, III, VII, XIV.

[38] Cf. P. A. Heelan, "Horizon, Objectivity and Reality in the Physical Sciences," *Internat. Philos. Qrtly.* 7 (1967): 375–412.

I have proposed elsewhere[39] the view that the notion of development can be analyzed in terms of the following ordering relationship between languages: L_1 (a language) is ordered to L_2 (another language) if and only if whatever can be truly said in L_1 can also be truly said in L_2. Such an ordering divides development into two classes. First of all, there is the relation between the members of a linear sequence of languages which unfolds in time the potentialities of a fixed heuristic structure. Let us call this sequence "a family of languages belonging to the same tradition." In this case the logical ordering relation is a simple ordering which also parallels the direction of time; the kind of development so defined characterizes what Kuhn has called "normal science."

Secondly, there is the relation between a manifold of non-communicating non-semantically linked) languages expressing disparate heuristic structures and a unified language in which the original languages communicate organically as sub-languages. In this case, the logical ordering relation is a partial ordering, parallel to the temporal ordering, which connects the early disparate traditions with the late unified tradition through a non-distributive lattice of languages.

I have proposed that the fulfillment of the non-distributive lattice condition be accepted as a sufficient and perhaps even a necessary condition of a progressive scientific revolution. However, it is still unclear whether or how the logical criteria just outlined of a progressive scientific revolution could be applied to the quantum mechanical case, for if my criticism of complementarity is correct, a revised account of QM descriptive language has still to be worked out and then adopted by the scientific community before the applicability of the model can be judged.[40]

The foregoing study of the development of quantum mechanics based upon the works of one of its principal authors has revealed layers of problems, mostly of an epistemological kind, that lie not far beneath the seemingly secure and unproblematic exposition found in most textbooks and accepted by most physicists. My purpose in bringing these problems to light is evidently not to discredit quantum mechanics, but to exhibit those hidden confusions and assumptions that leave it vulnerable. I have already expressed my belief elsewhere that not merely is

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[39] P. A. Heelan, "The Logic of Framework Transpositions," *International Philosophical Quarterly*, **11** (1971): 314–334. (Paper read at the Conference, *Ongoing Collaboration: First International Lonergan Congress*, April 1970).

[40] For a discussion of the meta-context logic of quantum mechanics, see P. A. Heelan, "Quantum Logic and Classical Logic: Their Respective Roles," *Synthese*, **22** (1970): 3–33; and "Complementarity, Context-Dependence and Quantum Logic," *Foundations of Physics*, **1** (1970): 95–110.

quantum mechanics defensible as a form of science, but that it is, perhaps, a model of the most sophisticated kind of human science that has been developed so far.[41]

This study has shown, however, that the co-existence of quantum mechanics with the older forms of science necessarily brings one or other (or both) into question. This crisis is a philosophical issue that physicists are not in general competent to discuss. It may well happen that quantum mechanics will be replaced because of contrary empirical evidence by a less controversial theory. But if it remains entrenched in physics, while at the same time remaining a scandal and a challenge to philosophy, attempts like the present one will surely be made to understand the source of the scandal and to remove it. It was while exploring the epistemological foundations of quantum mechanics that I rediscovered the revolutionary vision of reality glimpsed by Heisenberg in 1925 and lost soon after in Copenhagen. I hope that others too will discover this vision and that it may contribute towards the responsible development of quantum physics.

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[41] P. A. Heelan, *Quantum Mechanics and Objectivity*, *op. cit*.

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Appendix: Correspondence with Professors Werner Heisenberg and Francis Zucker

The letters to follow represent a selection of letters written to or from the author regarding the manuscript *The Observable*. I thank Professor Heidi Byrnes of the German Department, Georgetown University, for her translation from the German of Werner Heisenberg's letter. A copy of Heisenberg's original letter has been added.

FORDHAM UNIVERSITY
DEPARTMENT OF PHILOSOPHY
BRONX, NEW YORK 10458

Professor Dr Werner Heisenberg,
Director,
Max-Planck Institut für Physik und Astrophysik
München

28 February 1970

Dear Dr Heisenberg,

Two summers ago, in July 1968, we met at my request in your office, in the Institut, Föhringer Ring, to discuss some problems, mostly of a philosophical nature that arose out of the research I did for my book, *Quantum, Mechanics and Objectivity* (The Hague: Nijhoff, 1965). This book, my doctoral dissertation at the University of Louvain, was devoted to a study of your writings. Since I have come to the United States, I have come to realize that the style and interests of Angle-American philosophers of science are different from those of Europeans, and Professor Robert Cohen of Boston University persuaded me to write a book more in the style of current American philosophy on quantum mechanics, stressing the hermeneutics of your own scientific and non-scientific writings, and using the historical sequence of your writings as the central subject matter of the study. I have just finished this manuscript—it comes to approximately 50,000 words (200 typed pages)—and Professor Cohen is planning to publish it in a new series of monographs (University of Chicago Press) that should have considerable impact in the United States. The title I have chosen is THE OBSERVABLE: OBSERVATION, DESCRIPTION AND ONTOLOGY IN QUANTUM MECHANICS. I thought you would be interested to know of this. Moreover I should be delighted to give you a resumé of the book or a copy of the entire manuscript if your interest should go so far. Would you like to contribute a preface or a letter of introduction to the book? I expect the book will be read in all graduate departments of philosophy in the United States. Professor Cohen and I both think that the significance of your early work has been neglected, especially of "*Über quantentheoretische Umdeutung*..." and "*Über den anschaulichen Inhal* ..." There is a great interest in scientific (as well as other!) revolutions today!

With great respect, I am
Yours sincerely,
Patrick A. Heelan, S. J., Ph.D, Ph.D.

MAX-PLANCK-INSTITUT FUR PHYSIK UND ASTROPHYSIK
INSTITUT FOR PHYSIK
8 MUNCHEN 23,

den 10, Nov. 1970

Prof. W. Heisenberg
FÖHRINGER RING 6 **TELEFON** 327001–015 **327 001**

Herrn
Professor Patrick A. Heelan
Fordham University
Bronx, N.Y. 10458, USA

Sehr verehrter Herr Heelan!

Diesen Brief muß ich mit einigen Entschuldigungen beginnen; erstens weil ich auf Deutsch schreibe$_s$ da es mir etwas bequemer ist und Sie, wie ich weiß, Deutsch ohne Schwierigkeit lesen können; dann weil ich Ihnen erst so spät auf das Manuskript Ihres neuen Buches antworte. Ich war in diesem Sommer viel auf Reisen, anschließend eine Zeitlang krank, so daß ich das Studium Ihres Buches immer wieder verschieben mußte.

Ich habe mich über die Lektüre Ihres Buches sehr gefreut. Gerade die Verbindung einer Schilderung der historischen Entwicklung mit einer sehr sorgfältigen philosophischen Analyse scheint mir eine glückliche Voraussetzung dafür, daß der Leser in die Quantentheorie und ihre Philosophie wirklich eindringt. Sie haben völlig richtig bemerkt, daß bei Bohr und mir die philosophischen Voraussetzungen von Anfang an etwas verschieden waren. Wir sind in verschiedenen philosophischen Traditionen aufgewachsen, außerdem spielt wohl auch die angeborene Veranlagung eine Rolle. Für mich war die mathematische Form immer die Voraussetzung für eine Ontologie; Bohr war an dieser Stelle wohl immer mehr ein reiner Empiriker. Bei den wirklich schwierigen Fragen der Quantentheorie haben Sie—darüber habe ich mich besonders gefreut—sehr sorgfältig und vorsichtig formuliert. Ich habe Ihre Abschnitte über die Reduktion der Wellenpakete mit großer Befriedigung gelesen, weiß aber immer noch nicht, ob ich mit allem völlig einverstanden bin. Aber in einer Korrespondenz könnte man diese subtilen Probleme doch nicht bis zu Ende diskutieren.

Sie haben in der Regel die Sprache mit der ganzen Schärfe anzuwenden gesucht, die die heutige Logistik dafür fordert und bereitstellt. Das ist sicher absolut nötig in einem Land, in dem das logistische Präzisionsdenken eine dominierende Rolle in aller Philosophie spielt; aber ich kann nicht leugnen, daß es mir immer etwas “gegen den Strich” geht, vielleicht nur weil ich diese Art der Sprache selbst nur sehr unvollkommen beherrsche, vielleicht aber auch, weil ich dieser scharfen Sprache etwas mißtraue. Könnte nicht die Forderung der Schärfe gelegentlich die Aufmerksamkeit in die falsche Richtung lenken? Aber für Ihr Buch war es sicher richtig, sich hier dem angelsächsischen Denken anzupassen; besonders weil Sie sich ja sonst in den weiteren Bereichen der Philosophie mit voller Sicherheit bewegen. Also haben Sie noch einmal den herzlichsten Dank fűr Ihr Manuskript. Ihr Buch wird sicher einen wichtigen Beitrag zum Verständnis der Quantentheorie in den weitesten Kreisen leisten.

Mit gleicher Post schicke ich Ihnen noch ein Buch, das ich vor einem Jahr veröffentlicht habe and in dem ich die von mir miterlebte Geschichte der Atomphysik in Form von Gesprächen schildere. Eine englische Űbersetzung des Buches soll nächstens erscheinen, liegt aber noch nicht vor.

Mit vielen guten Wünschen
Ihr
W. Heisenberg

MAX-PLANCK INSTITUT FŰR PHYSIK UND ASTROPHYSIK

Institut für Physik
8 München 23, 10 Nov. 1970
Föhringer Ring 6
Phone 327001

Professor Patrick A. Heelan
Fordham University
Bronx, NY 10458, USA

Dear Professor Heelan!

I must begin this letter with some apologies; first, because I am writing in German since I am somewhat more comfortable with it and you, as I know well, have no difficulty reading German; then also because I am so late in responding to the manuscript of your new book [*The Observable**]. I have been travelling a lot this summer, then was ill for some time, which meant that I was repeatedly forced to put off studying your book.

---

* This was the original title of the manuscript that Heisenberg read; no changes have been made in the printed text that he approved.

I have very much enjoyed reading your book. Precisely the combination of an account of the historical development with a very careful philosophical analysis seems to me to be a felicitous precondition for the possibility that readers will be able to really delve into quantum theory. You were quite correct in observing that the philosophical assumptions for Bohr and me were somewhat different right from the beginning. We grew up within different philosophical traditions, and in addition our inborn predilections probably also played a role. For me, mathematical form was always the precondition for an ontology; on this matter Bohr most likely was always a pure empiricist. With regard to the really difficult questions of quantum theory you used very precise and careful phrasing—something I noted with particular pleasure. I read the passages on the reduction of the wave packet with great satisfaction, however still don't know whether I completely agree with everything. But in a correspondence such as this one it would not be possible, in any case, to discuss these subtle problems toward attaining a resolution.

You have, in general, sought to apply with the greatest precision the kind of language that contemporary Logic demands and makes available. That is surely absolutely necessary in a country in which thinking with logical precision plays a dominant role in all of philosophy; but I cannot deny that for me this always goes a bit against the grain, perhaps merely because I myself command this kind of language only imperfectly, but perhaps also because I somewhat distrust such precise language. Couldn't the demand for precision on occasion misdirect our attention in the wrong direction? But for your book it was surely the right decision in this case to accommodate Anglo-American thinking; all the more so as you otherwise move with complete command through other areas of philosophy. So, please accept my heartfelt thanks for your manuscript. Your book will certainly make an important contribution toward an understanding of quantum theory in the widest circles.

I am also sending you by the same post a book** that I published a year ago and in which I use conversations to tell the history of atomic physics as I experienced it in my own life time. An English translation of the book is scheduled to appear soon, however at this point is not yet available.

With many good wishes
Your
W. Heisenberg

** Heisenberg, *Der Teil und das Ganze—Gespräche im Umkreis der Atomphysik* (Munich: Piper, 1969); in English as *Physics and Beyond: Encounters and Conversations*. A. J. Pomerans, trans. (New York: Harper & Row, 1971).

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November 27, 1972

Prof. Patrick Heelan, S. J.
Chairman, Dept. of Philosophy
S.U.N.Y.
Stony Brook, New York

Dear Professor Heelan:

I should long ago have answered your letter with the invitation to visit Stony Brook for a philosophical chat—which I would love to do. …..

Only two weeks ago I found out upon arrival of the Boston Colloquium Program, that you are to be my commentator or on December 12. I was immensely pleased by this information. I had written to Bob Cohen during the summer, when asked, that you would be by far the most competent man to judge me, but I hadn't really dared hope for you because I thought that Bob would want to choose an anti-phenomenologist. My text which really isn't in typed form yet is (perhaps, unrecognizable) elaboration of the sentence on p. 91 of [Husserl,] *Ideen III* the "*jede schlichte Anschauung 'birgt in sich' das Wesen der Ihr entsprechenden Region…Umgekehrt ist es evident, das der Begriff der Region…gültig anwendbar ist als phänomenologisch bescheibender Begriff für die betreffende Anschauung …*" and of the equivalent sentence on p. 161 (English edition; p. 144 in the German text) of *Formal and Transcendental Logic* about the perfect correlation between the category of evidence and the category of objectivity. See also pp. 21–23 and 101–103 of *Ideen III*. I will also refer to a thesis by Drieschner done under Weizsäcker, and perhaps you may wish to glance at it, so I am airmailing it to you under separate cover. You will get the idea of it by reading the introduction, which comes in two versions, one of them rendered in somewhat more readable English (by me) than the rest of the thesis. Should you arrive a bit early in Boston on Dec. 12, you could still read the text there (but I don't think it's important). Let Betsy McCoy of the Department of Physics be our go-between. She will know my hotel name and where I'll be that afternoon.

Heisenberg at a party last summer said he thought very highly of your book. At the time I supposed that he meant *Quantum Mechanics and Objectivity*, but then your fascinating new manuscript came and I began to wonder whether he was in effect giving his imprimatur on that. That would please me because you are saving Heisenberg in that work from his own compromising, and I like to think of his pleased expression as he mentioned your book was prompted by gratitude for that deed of yours. I thank you also for a copy of your talk early this Fall in Dublin, I think, I don't have it with me here. It gave me a very clear idea of your position.

Very sincerely,
Francis Zucker

* * *

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Patrick Aidan Heelan: Brief Biography Including Select Bibliography

Biographical Note

Patrick Aidan Heelan (17 March 1926–1 February 2015) was born in Dublin, Ireland. He grew up not too far from the Martello Tower in Sandy Cove—names known to readers, of course, from the works of James Joyce, another Dubliner. Heelan attended Belvedere College as a boy and joined the Society of Jesus at 16, taking his B.A. in 1947 and his M.A. in 1948, all with first-class Honors, in both mathematics and mathematical physics at University College, Dublin during which time he also worked with Erwin Schrödinger and John Synge at the Dublin Institute for Advanced Studies, mathematicians famous for their work in General Relativity and Cosmology. In 1948, he won a Travelling Studentship that paid for doctoral studies abroad anywhere in the world. It was his Jesuit superior who directed him to take his doctorate in 1952 in geophysics and seismology at the Institute of Geophysics at St. Louis University as a junior Jesuit scholastic. Ordained in 1957, he taught physics at University College Dublin for several years before being asked by the Archbishop of Dublin to teach the philosophy of science. Patrick Heelan's sense that he needed more philosophy brought him, in two steps to an encounter, first off with Bernard Lonergan's 1957 book *Insight* (starting as he did with the original notes in Latin), and then after a two year post-doc working with Eugene Wigner at Princeton University at the Institute for Advanced Studies (1960–62), he also had his first experiences with the department of philosophy at Fordham University. Finishing his post-doc, Heelan returned to Europe to pursue a second doctorate in philosophy (September 1962–1964) at the Catholic University of Louvain at Leuven (in Belgium), where he specialized in the philosophy of science with a concentration on the philosophy of modern physics with a novel approach from the phenomenological and hermeneutical perspective of Husserl and Heidegger. Among others, he worked with Jean Ladrière, studying both logic and Husserlian philosophy (Jean Ladrière, himself a noted philosopher of mathematics and science, wrote the biographical entries on Patrick Heelan, including his first book, for the French *Encyclopédie Philosophique Universelle*). Heelan defended his second dissertation (with, as he was always pleased to report, *félicitations du jury*), published as *Quantum Mechanics and Objectivity* in 1965. During the same period he began his visits and correspondence with Werner Heisenberg himself Max-Planck Institute for Physics and Astrophysics in Munich, a contact Heelan maintained until Heisenberg's death in 1976.

In 1965, Heelan returned to the United States where he joined the Fordham University philosophy department. He left in 1970 to chair and to build the department of philosophy at the invitation of John S. Toll, the President of State University of New York at Stony Brook. There, over the course of the next 22 years, he would also serve in several positions in the administration of the University, including Vice-President. He published his second major study, *Space-Perception and the Philosophy of Science* with the University of California Press in 1983, which examines the geometry of vision including the space of art and experience and draws on Husserl, Heidegger, and Merleau-Ponty. Heelan was then recruited for Georgetown University as Executive Vice President for the Main Campus in 1992. Brought to the university by the then-president, his colleague and fellow Jesuit, the theologian and art theorist and critic, Leo O'Donovan, S. J., it was as Executive Vice-President at Georgetown that Heelan would come to befriend Jack DeGioia, who would later go on to become the first lay president of the university, along with the linguistics specialist, Heidi Byrnes with whom Heelan enjoyed a long and fruitful friendship and intellectual collaboration. At Georgetown, Heelan had many other intellectual interlocutors, including his fellow Husserlian John Brough as well as Wilfried Ver Eecke but also the Austiran born experimental neuroscientist, Karl Pribram and the cognitive scientist George Farre as well as the philosopher of science, Rom Harré whose work Heelan already engages in the pages above and whose instructive little book, *The Philosophies of Science* (Oxford, 1972) often served Heelan as one of the textbooks he liked to assign in his own courses on philosophy of science and in 1995, he was named the William A. Gaston Professor of Philosophy at Georgetown University.

2002 saw the publication of *Hermeneutic Philosophy of Science, Van Gogh's Eyes, and God: Essays in Honor of Patrick A. Heelan, S. J.* featured as Volume 225 in the Boston

Studies in the Philosophy of Science. A friend of music and enthusiastic devotee of the arts, a love of art that he shared affectively and theoretically with his good friend and Fordham colleague Irma B. Jaffe over many, many years. Patrick Aidan Heelan enjoyed travel all over the world, from the Hopi Indian tribe with which he spent an entire summer during his studies for his first doctorate to the towns and inns of Ireland which he visited with his brother Louis every summer until his brother's death. But before then he was able to include his brother and his sister-in-law Marie at a special centennial conference on the occasion of the Sesquicentenial of Friedrich Nietzsche's birth in 1994 at the Villa le Balze in Fiesole organized by the editor on the theme of Nietzsche and music. In his later years, he spent several summers with philosopher friends, including the editor as well as David B. Allison, William J. Richardson, S. J., Pina Moneta, Richard Cobb-Stevens, among others, in the South of France. He was very fond of Spain, and had a very close friend whom he prized as much for his poetry as for his origins, Antonio de Nicolás (the brother of the current Superior General of the Jesuits, Adolfo Nicolas) and Heelan had a special love for Italy, especially Santa Margherita di Ligure where his parents first went after they were married and to which all their children would be drawn: close to the secluded picture-book beautiful cove that uncurls into a slow arabesque along the coast before opening into its finish in the classic colors and hills of the port of Portofino. Patrick would continue to write on philosophy and physics and especially consciousness and entanglement but also to explore theology and to teach until he retired from the philosophy department in 2013, finally returned home to Dublin in 2014. He died surrounded by family and friends on a Sunday: 1 February 2015.

Credit: The editor draws on her memory and conversations with Patrick Heelan over a period of thirty-five years. Other sources consulted include Patrick Heelan's own reflections on his life entitled *'Le petit philosophe'* in: John C. Haughey, ed., *In Search of the Whole: Twelve Essays on Faith and Academic Life* (Washington, DC: Georgetown University Press, 2011), pp. 129–146.

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Patrick Aidan Heelan (1926–2015), a Jesuit priest, held a Ph.D. in geophysics and seismology (St. Louis University, 1952) and a Ph.D. in philosophy (Catholic University Leuven, 1964). He joined Fordham's philosophy department (1965), became chair of philosophy at Stony Brook (1970), served as Georgetown University's Executive Vice President (1992–1995), and taught philosophy (1995–2013). He is author of *Quantum Mechanics and Objectivity* (1965) and *Space-Perception and the Philosophy of Science* (1983).

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