

1965

# Quantum Mechanics and Objectivity - Table of Contents and Preface and Acknowledgments

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## Recommended Citation

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PATRICK A. HEELAN, S.J.

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# **QUANTUM MECHANICS AND OBJECTIVITY**

*A Study of the Physical Philosophy of  
Werner Heisenberg*



# QUANTUM MECHANICS AND OBJECTIVITY

# QUANTUM MECHANICS AND OBJECTIVITY

A STUDY OF THE PHYSICAL PHILOSOPHY OF  
WERNER HEISENBERG

*by*

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MARTINUS NIJHOFF / THE HAGUE / 1965



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PRINTED IN THE NETHERLANDS

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## PREFACE

Quantum mechanics has raised in an acute form three problems which go to the heart of man's relationship with nature through experimental science: (1) the public objectivity of science, that is, its value as a universal science for all investigators; (2) the empirical objectivity of scientific objects, that is, man's ability to construct a precise or causal spatio-temporal model of microscopic systems; and finally (3), the formal objectivity of science, that is, its value as an expression of what nature is independently of its being an object of human knowledge. These are three aspects of what is generally called the "crisis of objectivity" or the "crisis of realism" in modern physics.

This crisis is studied in the light of Werner Heisenberg's work. Heisenberg was one of the architects of quantum mechanics, and we have chosen his writings as the principal source-material for this study. Among physicists of the microscopic domain, no one except perhaps Bohr has expressed himself so abundantly and so profoundly on the philosophy of science as Heisenberg. His writings, both technical and non-technical, show an awareness of the mysterious element in scientific knowledge, far from the facile positivism of Bohr and others of his contemporaries. The mystery of human knowledge and human subjectivity is for him an abiding source of wonder. Heisenberg is far from the naive realism of the great scientists of the past, yet too much of an empirical investigator to espouse the deductionism of Spinoza and Leibniz which exerted such a pull, for example, on the elder Einstein. It is not surprising then that he situates himself uneasily within the perspective of critical philosophy, but of critical philosophy in crisis. For this reason, the modern European continental philosopher feels closer to him in spirit than does, perhaps, his Anglo-American counterpart.

The epistemology of quantum mechanics has up to now been studied almost exclusively through the works of Bohr and many studies and

doctoral theses exist in English of Bohr's philosophy. Heisenberg's philosophy has been curiously untouched. I surmise for a number of reasons. In the first place, he has always declared his attachment to the Copenhagen School and implied that he shared Bohr's philosophy of science. In fact, as this study shows, his philosophical outlook, except for a short period when he collaborated closely with Bohr, was very different and became increasingly so with the passage of time. In the second place, he is the most metaphysical of modern scientists and the genre of philosophical writing on physics in recent years has been dominated by a British and American school which tends to place metaphysics somewhere between mysticism and crossword puzzles.

The method employed exclusively in this work, and outlined in chapter one, is that of an analysis of "horizons", that is, of the kind of cognitive intentionality-structure implicit in the conduct of a systematic investigation. The kind of investigation we are interested in is, of course, a scientific investigation. An intentionality-structure is composed of a noetic and a noematic aspect which are correlative to one another. The noetic aspect is an open field of connected scientific questions addressed to empirical experience; the noematic aspect is the response obtained by scientific experiment from experience. The totality of actual and possible answers constitutes a horizon of actual and possible objects of human knowledge and this we call a *World*. The World is the source of meaning of the word "real". "Real" is then defined as what makes its appearance directly or indirectly as one of the objects in the World. But as objects can be of many kinds, the sense of "real" also is ambiguous. We find it necessary to distinguish different classes of objects: public and private objects, intelligible and sensible objects, empirical, phenomenal and bodily objects, objects of mere thought or supposition and, finally, objects in the strict (or formal) sense which are affirmed as *beings* or *noumena*.

We found it necessary to distinguish *reality* from the *criterion* of reality for us, and *real* from *being*. The two traditional extremes of empiricism and rationalism can then be defined with respect to the horizon of objects conceived to constitute the World of real things. Empiricism identifies the *real* with *being* and both with objects of empirical intuition, that is, with bodies. The meaning of real and the criterion of reality are identified. Rationalism identifies *being* with *intelligible object*, and tends to employ the term "real" for the object of empirical intuition, which, however, is regarded as alien to being. With this schema, it is possible to trace the movement of Heisenberg's

thought, that is, the changing meaning he gave to such key words as *reality*, *being* and *objectivity*, during the critical period of the development of quantum mechanics and the subsequent modification of his position as he grew older.

Our point of departure is the horizon of classical physics into which Heisenberg entered as a young student and which is the epitome of extreme rationalism.

Chapter two is an account of the historical origin of the quantum theory in its two forms; the quantum mechanics of Werner Heisenberg and the wave mechanics of Erwin Schrödinger. Heisenberg's discovery of quantum mechanics was accompanied by a dramatic insight into the structure of physical science: a quantity which could not be observed in principle (a non-observable quantity) should not be part of a physical theory. This discovery brought about the first major change in the intentionality-structure of physics since the time of Galileo. Heisenberg's master-insight implied a conversion from the rationalist intentionality characteristic of classical physics to a predominantly empiricist one. A major influence in the explicit formulation of this change of outlook was Bohr whose *principle of complementarity* was eventually (and reluctantly at first) accepted by Heisenberg.

In chapter three, we analyse the philosophy of complementarity as sketched first of all in Bohr's works and then in the early writings of Heisenberg. We find that it includes a theory of scientific method, and a philosophical outlook on *reality*, *objectivity* and *causality*.

In chapters four and five, we are concerned with an exposition and critique of the complementarity account of scientific method. In the first place, complementarity states that our concepts of physical properties have basically the same logical structure as those of everyday life. This thesis, depends upon a theory of knowledge called *psycho-physical parallelism*. We show that there are two logically different sets of concepts in every physical theory; a set founded upon relations *to us* (*operational* and *observational concepts*) and a set founded upon relations *to things* (*explanatory concepts*). Because of this, psycho-physical parallelism is not a satisfactory account of scientific knowing. Moreover, the place of *observable symbols* (pointer readings, etc.) and their counterpart in *mathematical symbols* is not sufficiently accounted for in the complementarity view of scientific method.

The second problem in scientific method concerns the function of the measurement process in physics. Heisenberg implies that, since it is part of the activity whereby we contact and so observe physical reality,



it has a disturbing effect on reality and tends to limit our access to the objective properties of atomic realities (*This is the perturbation theory of measurement*). In keeping with the distinctions we have made between properties-for-us and properties-for-things, we assert that the measuring process is essential to the definition of a physical property as a property-for-things. Hence the so-called perturbation is an essential element in its definition; it is not extrinsic to the objective property nor has it anything to do with a limitation of our access to physical reality.

The third problem (chapter five) in scientific method concerns the *public objectivity* of quantum mechanics. Heisenberg asserts the inescapable presence of a "subjective element" in the quantum theory. By this he means two things: (i) the failure of the (Kantian) category of "substance" for an atomic system (from which it follows that an atomic system cannot be given a "realistic" description of universal validity, i.e., for all observers), and (ii) that the act of observation – as a *private conscious act* – resulting in the "reduction of the wave packet" effects the suppression of physical correlations (or superposition states) and so changes a physical aspect of reality.

With respect to (i), we answer by distinguishing between the *observable symbol* (which may or may not constitute a coherent causally related phenomenal object) and the *thing or property symbolised* (whose consistency is to be judged by the non-contradictory character of the mathematical theory, and whose reality is manifested through an observable symbol). With respect to (ii), we defend the view that the formation of a *mixture* from a *pure case* is a logical operation determined by the antecedent choice of the kind of experimental data to be observed and that any physical changes effected are consequences of the activity whereby the measuring instruments are set up and the results obtained.

The intervention of the scientist-observer's subjectivity then is no different in quantum physics than in classical physics. The nature of the quantum physical object, however, is different; for, while in classical physics this is an *idealised normative* (and hence *abstract*) object, in quantum physics the object is an *individual instance of an idealised norm*. In classical physics, differences of individual instances from the ideal norm are treated by a statistical "theory of errors"; in quantum physics the "errors" of conjugate properties are found to be concretely linked and for this reason the statistical part of a quantum mechanical explanation cannot be separated from its non-statistical

part. An atomic system, then, is represented in the quantum theory by a *virtual ensemble* in which both the physical variables (as properties-or-things) and their distributions about their means (or expectation values) are linked within one unitary formalism. The *Indeterminacy Relations* are expressions of the *concrete character* of the object of quantum mechanics and of the interrelated character of the "errors" of conjugate quantities.

During the course of our attempt to separate the physiognomy of the *strict object* from the matrix of scientific methodology in which it makes its appearance, we demonstrate the thesis that *no* physical thing or property in so far as this is an explanatory element in physics – whether it be in classical or in quantum physics – is *per se* representable in sensibility (i.e., *per se* observable). It becomes *per accidens* observable only through the occurrence of appropriate *observable symbols* associated unambiguously with the physical object in question.

In chapter six, we discuss various opinions on the essence of the *Correspondence Principle* which relates classical and quantum physics in *limiting cases*. We point out that the ambiguity in the various views is due to the multiplicity of possible limiting processes by which a classical theory can be obtained from a quantum theory; for besides the vanishing of the quantum of action limiting procedures can also be applied to the rules of correspondence (or interpretation) which link the mathematical formalism to experimental observations. For example, if the quantum rules are retained, then a classical statistical particle theory is obtained: if, however, the quantum rules are changed so as to make the operators correspond to numerical averages of quantities taken over a small interval of time at a given epoch, then classical particle mechanics is obtained. On the basis of these considerations we vindicate the *completeness principle* for the quantum theory.

Part II, comprising chapters seven, eight and nine, is concerned with the ontological structure of atomic systems. Chapter seven examines various notions current among physicists on the meaning of *reality* and its *criterion for us*. These are divided for convenience into two classes: one of predominantly *rationalistic* tendency of which Einstein (Senior) is chosen as a classic example, and another of predominantly *empiricist* tendency, illustrated by some aspects of Wigner's thought.

In chapter eight, we consider Heisenberg's ontology at length. From an early and predominantly empiricist phase, he passed to a predominantly rationalist viewpoint on nature; not, however, back to the rationalism of Cartesian mechanism, but to one inspired almost totally

by the transcendental philosophy of Kant. We find that he is also strongly influenced by Plato, while his more recent adoption of Aristotelian terminology (of the terms *dunamis* or *potentia*, and *universal* or *primary substance* or *matter*) does not really indicate a significant change in his outlook. It provided him, however, with a solution to the problem of what noumenal reality to associate with a quantum mechanical system like an elementary particle. The noumenal reality associated with a quantum mechanical system is, he says, a *dunamis* (or *potentia* or *objective tendency*) related to the act of observation. The act of observation completes its actuality by actualising one of the possibilities (or eigenstates) represented by its state vector. Heisenberg also identifies *energy* with Aristotelian *primary matter*. Heisenberg's *Practical Realism*, as he calls his philosophy, remains however a Kantian type idealism.

In chapter nine, we present our solution to the problem of the *objective realism* of a scientific theory. First of all, the notion of *reality* is examined in the light of the polymorphism of human cognitive activity. This enables us to overcome the fundamental and unharmonised duality (part empiricist and part rationalist) in Heisenberg's thought. We show that the structure of human cognitive activity is realistic. We next examine the relationship of a part (e.g., the nucleus) to the whole (e.g., of an atom) in a compound microscopic system. We find that the part is not an *actual part*, but can be called a *virtual part*. We examine also the function of energy in physics as a universal invariant. We find that energy has not the properties of an Aristotelian prime matter, but is a condition of possibility characteristic of a particular physical milieu and that it governs the kinds of systems and processes permitted by the milieu.

In Part III (or chapter ten), we gather together synthetically the clues suggested by the preceding analysis on the logical structure of a physical theory. We find that physics as a science depends upon the articulation of two Worlds: a World-for-us (described by *operational* or *observational concepts*) and a World-for-things (described by *explanatory concepts*). The duality of World explains the use by the physicist of two languages: an *observation language* and an *explanatory language*.

## ACKNOWLEDGMENTS

The author wishes to thank Monsignor Louis de Raeymaecker, President of the *Institut Supérieur de Philosophie*, and vice-rector of the Catholic University of Louvain, together with the professional staff of the *Institut*, for the instruction, guidance and inspiration to which the author owes so much. The author wishes also to express his indebtedness to Fordham University, New York, and to Princeton University, New Jersey, where, as a Visiting Fulbright Fellow, he prepared the scientific part of this work. In the collegiate chapel on the campus of Princeton there is a transept window dedicated to the benign patrons of learning. Among these, fittingly, with Augustine the philosopher-theologian and Bacon the scientist, Cardinal Mercier, founder of the *Institut Supérieur de Philosophie* is immortalised.

The author owes a warm personal tribute of respect, admiration and gratitude to Professor Jean Ladrière of the Catholic University of Louvain, who in 1959 encouraged him to undertake this work and then, while generously making available to him his own great learning, left him nevertheless entirely free to pursue the insights out of which this book eventually came. This work was presented as a doctorate thesis to the Catholic University of Louvain in 1964.

The author also wishes to thank the Very Reverend Charles O'Connor, S.J., Provincial, for making time and resources available for this research; Professor Eugene Wigner of Princeton University for many valuable conversations on the epistemology of quantum mechanics; M. H. Heelan, Esq., for the infinite patience with which he reviewed the style and expression of the manuscript; and Mrs Irene Sheils for typing the manuscript so expertly thereby relieving the author of so many pains.

*Fordham University, 1965*