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Classes of Copenhagen interpretations: Mechanisms of collapse as typologically determinative

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ABSTRACT

The Copenhagen interpretation of quantum mechanics is the dominant view of the theory among working physicists, if not philosophers. There are, however, several strains of Copenhagenism extant, each largely accepting Born's assessment of the wave function as the most complete possible specification of a system and the notion of collapse as a completely random event. This paper outlines three of these sub-interpretations, typing them by what the author of each names as the trigger of quantum-mechanical collapse. Visions of the theory from von Neumann, Heisenberg, and Wheeler offer different mechanisms to break the continuous, deterministic, superposition-laden quantum chain and yield discrete, probabilistic, classical results in response to von Neumann's catastrophe of infinite regress.

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1. Introduction (a)

Not long after the quantum theory was introduced, efforts were made to give a satisfactory interpretation of it. Today there is a blizzard of interpretations ranging from, among others, no-collapse modal theories, no-collapse dualistic theories, collapse theories incompatible with Schrödinger's equation, and various interpretations falling under the umbrella of Copenhagen interpretations. Of these, the Copenhagen school has risen to prominence. This view of the theory is ubiquitous in physics textbooks, and it is the received view of the average working physicist, but it is perhaps surprising that there are so many versions of Copenhagenism in circulation—sub-interpretations of the dominant interpretation. The present essay concentrates on analyses generally attributed to three men who worked within the Copenhagen tradition and tried to make sense of the theory within these strictures. Werner Heisenberg, John von Neumann, and John Wheeler all lay out different visions of the theory, but it seems at first blush uncontroversial to describe each as a Copenhagenist (each sub-theory has its own set of associated problems, but it is not the purpose of this project to investigate these difficulties). Because of the plethora of Copenhagen interpretations extant, there is a need to catalogue and categorize them. This paper is an attempt at starting this process in a rational way.

Others, of course, have made clear that there is not one, monolithic "Copenhagen Interpretation" (see Beller, 1999; Howard, 2004; Scheibe, 1973), and Don Howard has argued convincingly that even the term "Copenhagen Interpretation" is a misnomer, being a creation of Heisenberg for self-serving purposes (Howard, 2004, p. 677). According to Howard, the interpretation that has become thus known bears only partial resemblance to what Bohr actually thought (Howard, 2004, p. 669). Hence, claims to the existence of a variety of Copenhagen interpretations made here are not meant to be taken as original. Rather, the point here is to categorize these different interpretations.

David Bohm, who later abandoned the Copenhagen view, set out the standard assumptions of canonical reading of the interpretation popularly credited to Bohr succinctly:

(1) The wave function with its probability interpretation determines the most complete possible specification of the state of an individual system.

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(2) The process of transfer of a single quantum from observed system to measuring apparatus is inherently unpredictable, uncontrollable, and unanalyzable. (Bohm, 1983, p. 372)

In short, the way the Copenhagen interpretation is generally viewed may be summarized in the following way:

(1) The wave function is the most complete description possible of a quantum system.
(2) The Born (probabilistic) interpretation of the wave function is correct.
(3) Quantum-mechanical collapses occur (the collapse postulate is correct).
(4) Quantum-mechanical collapses are not amenable to analysis.

It is important to note for the purposes of this paper that when collapses are described as not analyzable, this is intended in the sense of ''irreducibly statistical.'' It will be seen that Heisenberg, von Neumann, and Wheeler each offer an analysis of collapse, but that this will not run counter to characteristic (4) above on the given interpretation. It will also be seen that all four men (Bohr, von Neumann, Heisenberg, and Wheeler) concur on the other tenets of Copenhagen faith. Bohr himself chose not to investigate quantum-mechanical collapse, believing that complementarity and entanglement were the fundamental concepts involved (Howard, 2004, pp. 670–671). He rejected the notion that collapse was a real phenomenon, taking it to be an artifact of the formalism, the purpose of which ''is not to disclose the real essence of the phenomena but only to track down … relations between the manifold aspects of our experience'' (Bohr, 1961, p. 18). Von Neumann, Heisenberg, and Wheeler, on the other hand, believed that collapse is real and subject to some degree of study, particularly as far as naming a mechanism for collapse is concerned. That is, Heisenberg, von Neumann, and Wheeler accept that quantum-mechanical collapses do occur and that they do not occur spontaneously. Further, they all hold that these collapses are amenable to some form of analysis and that a catalyst for the collapse can be found.

2. A brief note before proceeding

Before further progress can be made, honesty compels the admission that things are not as cut-and-dried as the previous paragraph implies. In fact, it should not be surprising that there is no unanimity among philosophers of science as to what positions were actually held by von Neumann, Heisenberg, and Wheeler (further, there is much debate as to who actually came up with what is now called the Copenhagen interpretation and what, precisely, it is). True, there are canonical readings of each man's work, that is, dominant interpretations of their interpretations, but none is assented to by all interested parties. The least of the problems this creates is just how it is that one is supposed to refer to the various theories in play. For instance, the standard reading of von Neumann is that he believed an observer was necessary to collapse the wave function. Shall this be called ''von Neumann's view,'' ''the standard interpretation of von Neumann's view,'' or should a new moniker be applied to this theory that is neutral as to a connection with von Neumann's actual beliefs?

Taking these in reverse order, Nick Herbert actually does apply new names to each interpretation in his *Quantum Reality*: von Neumann's view becomes the ''All-Quantum Interpretation'' (Herbert, 1985, p. 146), Heisenberg's view is the ''Copenhagen Interpretation Part I'' (Herbert, 1985, pp. 158–159), and Wheeler's vision of reality is dubbed Copenhagen Interpretation Part II, the ''Austin Interpretation'' (Herbert, 1985, p. 164). As these names are not widely accepted, they will not be used here. Next, applying the prefix ''the canonical reading of'' or ''the standard view of'' to, say, ''von Neumann's view'' is linguistically just too ugly to contemplate. Thus, for the sake of clean exposition, and perhaps at the expense of accuracy, the standard reading of von Neumann's view will be termed ''von Neumann's view'' where possible (and similarly for the others). At the same time, care will be taken to discuss alternate readings of these accounts.

In the end, the purposes of this paper will be unaffected. It is the purpose of this essay to investigate and categorize different interpretations of quantum mechanics regardless of who did (or did not) actually espouse them. While von Neumann may or may not have *really* believed what will here be called von Neumann's interpretation (again, because it is the dominant reading of his work), that interpretation (Herbert's ''All-Quantum Interpretation'') is the actual subject for study. *Mutatis mutandis* for the rest.

3. Introduction (b)

One way to interpret the work of these men to be considered here is to take it as an answer to the question, ''What is a measurement?'' If one reads ''not amenable to analysis'' in an absolute sense, a measurement becomes ''that which collapses the wave packet,'' or ''that which yields discrete, classical outcomes from continuous, quantum processes.'' Each man in the present work tries to supply a more satisfying response. Von Neumann, Heisenberg, and Wheeler all seek a non-quantum entity to break the chain of quantum entities starting with the observed system and ending with the observer, though the nature of these entities differs for the three men: Heisenberg and Wheeler merely need macroscopic objects, a measuring device and a record of a measurement, respectively, and von Neumann invokes the human mind to accomplish the task. This is necessary to the extent that if all objects are to be bound by the rules governing the behavior of the very small, no collapses will ever occur, and superpositions will be a fact of everyday life. Needless to say, this runs counter to experience, so to save the phenomena of the laboratory, these entities are postulated to be necessarily classical. While this analysis of collapse is a break with Bohr, it seems madness to deny that the scientists considered here are his intellectual heirs (or at least Heisenberg's version of him). Thus, each of these scientists breaks with Bohr in trying to give some analysis of the measurement problem by giving an account of what catalyzes quantum-mechanical collapse since each takes collapse to be a physically real aspect of the theory; this is the philosophical importance of their research. Further, one can see that their work opens the door to typing different Copenhagen interpretations based on proposed mechanisms for collapse.

In examining how each theorist's vision of quantum mechanics handles the demands of what has been seen in laboratories across the world, it will be necessary to understand von Neumann's ''catastrophe of infinite regress,'' as the work examined here is a direct response to this particular conundrum. It may be fairly said that the philosophical work of the three men considered is defined by their responses to von Neumann's problem. An example will be useful in clarifying what is at issue. In the discussion that follows, only the narrowest application of the collapse postulate will be employed, and any straying from the formalism governing quantum evolution will be kept to a minimum.