The Heisenberg Interpretation of Quantum Mechanics (Extended Abstract)

Armin Nikkhah Shirazi *

University of Michigan, Department of Physics, Ann Arbor

January 31st, 2020

1 Introduction

In *Physics and Philosophy: The Revolution in Modern Science*, Heisenberg made an ontic distinction which is encapsulated in the following passage:

> In the experiments about atomic events we have to do with things and facts, with phenomena that are just as real as any phenomena in daily life. But the atoms or the elementary particles themselves are not as real; they form a world of potentialities or possibilities rather than of things or facts.(p. 160)

Clearly, for Heisenberg there is a quantum-classical dualism, and furthermore, it is grounded in an ontological dualism in which the duals are mutually exclusive. However, no corresponding dualism can be found in the mathematical formalism of quantum mechanics. Here, we present an attempt to formally implement it.

2 Heisenberg's Distinction in Classical Probability

As a warm-up to implementing Heisenberg's distinction in quantum mechanics, let us first implement it in classical probability. Consider the following: I hold a fair six-sided die in my hand, ready to throw it. The possible outcomes can mathematically be considered as elements of a fiber of six potentialities on the actual outcome of a throw. So, to generalize, we need to define two distinct sets, one which represents outcomes as 'potentialities or possibilities' and another one which represents outcomes as 'things or facts', such that that the former is a fiber on each element of the latter. I prefer the term 'actualizability' over 'potentiality' because the latter has many different connotations whereas the former does not, which allows the former to be associated rather exclusively with Heisenberg's distinction. To implement this formally, add new structure and a zeroth axiom (underlined) to Kolmogorov's axioms (Kolmogorov, 1950):

> Let $\Omega = \bigcup_{i=1}^{N} E_i$ be a set where N is either finite or countably infinite, $\mathcal{A} \subseteq \mathcal{P}(\Omega)$ a set of its mutually exclusive subsets E_i, and call the pair $(\Omega, \mathcal{A})$ a measurable space. <u>Let $\Gamma = \{f(\omega)\}$ be a set where $f : \Omega \to \Gamma$ is a bijection</u>. A real-valued function $P : \mathcal{A} \to \mathbb{R}$ satisfying
>
> - <u>Axiom 0: Ω is a fiber on each $\gamma \in \Gamma$</u>
> - Axiom 1: $0 \leq P(E_i) \leq 1$
> - Axiom 2: $P(\Omega) = 1$
> - Axiom 3: $P \bigcup_{i=1}^{N} E_i = \sum_{i=1}^{N} P(E_i)$
>
> is called a *probability*.

The implementation is trivial but addresses a well-known problem in the foundations of probability, namely that Kolmogorov's axioms do not in any way distinguish a probabilistic measure from non-probabilistic unit measures such as unit lengths or volumes. This can give rise to confusion,

*armin@umich.edu

as can be seen by the fact that if we accepted the zeroth axiom, we would end up defininng non-probabilistic unit measures by omitting axiom zero, *yielding nothing other than our* ***current*** *definition of probability.*

3 The Heisenberg Interpretation Postulates

The implementation of Heisenberg's ontic distinction in quantum mechanics is analogous to what was just done in classical probability: its standard postulates (Shankar, 1994) are modified by the minimum necessary in order to accommodate his distinction (modifications are again underlined). This modified set of postulates is what I call the Heisenberg Interpretation of Quantum Mechanics (HI):

- *Postulate* 0*:* The L^2 complex Hilbert space $\mathcal{H}$ is an actualizability space.
- *Postulate* 1*:* The physical states of a quantum systems are completely represented by elements of $\mathcal{H}$, denoted by Ψ.
- *Postulate* 2*:* Observables are represented by linear Hermitian operators acting on the elements of $\mathcal{H}$.
- *Postulate* 3*:* The time evolution of an element Ψ of $\mathcal{H}$ is given by the Hamiltonian.
- *Postulate* 4*:* A "Measurement" of the property of a state is represented by a map $\mathfrak{E} : \mathcal{H} \to \mathcal{C}$, where $\mathcal{C}$ is the collection of all basis states of $\mathcal{H}$ in all bases as actualities, which will be called *'classical states'*, and $\mathfrak{E}$ will be called the *actualization map*. The image of the map domain is denoted $\mathcal{B} \subset \mathcal{C}$, the collection of basis states as actualities in the measurement basis.
- *Postulate* 5*:* The Probability of obtaining a classical state $\mathfrak{E}(\Psi)$ upon a measurement of Ψ is given by the Born Rule.
- *Postulate* 6*:* The Completion of a measurement is represented by the map $\mathfrak{S} : \mathcal{B} \to \mathcal{H}$ such that $\mathfrak{S}(\mathcal{E}(\Psi)) = \psi$, an eigenstate of Ψ, where $\mathfrak{S}$ will be called the *deactualization map.*

The HI is not meant to make any operational changes to how quantum mechanics is used, save possibly for situations involving quantum measurements and state reduction, for it models those clearly very differently. Figure 1 gives an overview of how state reduction is conceptualized under the HI:

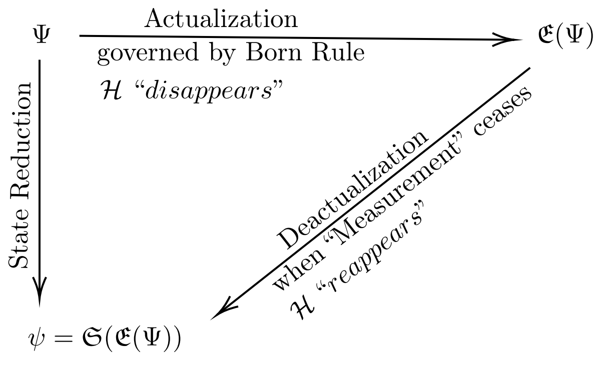

Figure 1: In standard quantum mechanics, there is just state reduction upon a "measurement", but under the HI this is the result of the composition of two maps which model the actualization and deactualization of a classical state. Notice that while the state is classical, there is no Hilbert space involved in its representation because the state is not one of its elements.

4 Advantages over the Copenhagen Interpretation

The Heisenberg Interpretation can be considered a variant of the 'Copenhagen Interpretation' (though there is in reality no single such interpretation) but offers a number of advantages over other variants which are discussed in the full paper but only outlined in this abstract:

1. The HI eliminates a possibly incoherent aspect of the Copenhagen interpretation which involves mixing representations of actualities with actualizabilities.
2. The HI circumvents the violation of unitary time evolution in the standard quantum formalism.
3. The HI grounds the 'Heisenberg cut' directly in the quantum formalism
4. The HI directs attention to a feature absent in the standard formalism: deactualization.
5. The HI may provide a refinement for the scope of quantum decoherence
6. The HI reframes quantum non-locality in terms of correlated actualization.
7. The HI may set the stage for yielding novel experimental predictions pertaining to the relationship between gravity and the quantum.

5 Conclusion

The HI implements at the level of mathematical formalism a distinction into quantum mechanics which has heretofore only been expressed in words. A major outstanding problem is that a "measurement" is still treated as a black box. If this distinction is really "out there" in reality, then the interpretation points toward a deeper theory, a successor to quantum mechanics in which the elucidation of the black box of measurement comes out of the mathematical structures themselves.

References

[1] Heisenberg, W. (1958) *Physics and Philosophy: The Revolution in Modern Science.* London: George Allen & Unwin

[2] Kolmogorov, A. (1950) [1933]. *Foundations of the theory of probability.* New York: Chelsea Publishing Company

[3] Shankar, R. (1994). *Principles of Quantum Mechanics,* 2nd. ed. New York: Plenum Press