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The Consistent Histories formalism and the measurement problem

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ABSTRACT

In response to a recent rebuttal of Okon and Sudarsky (2014b) presented in Griffiths (2015), we defend the claim that the Consistent Histories formulation of quantum mechanics does not solve the measurement problem. In order to do so, we argue that satisfactory solutions to the problem must not only not contain anthropomorphic terms (such as *measurement* or *observer*) at the fundamental level, but also that applications of the formalism to concrete situations (e.g., measurements) should not require any input not contained in the description of the situation at hand at the fundamental level. Our assertion is that the Consistent Histories formalism does not meet the second criterion. We also argue that the so-called *second* measurement problem, i.e., the inability to explain how an experimental result is related to a property possessed by the measured system *before* the measurement took place, is only a *pseudo-problem*. As a result, we reject the claim, defended in Griffiths (2015), that the capacity of the Consistent Histories formalism to solve it should count as an advantage over other interpretations.

1. Introduction

The Consistent Histories (CH) framework provides a formulation of quantum mechanics that assigns probabilities to histories of all kinds of systems, microscopic and macroscopic, using a single universal machinery and without "Heisenberg cuts" or references to measurements or observers. As a result, proponents of CH maintain that the formalism overcomes the measurement problem of the standard interpretation (as well as *all* other standard quantum paradoxes). In Okon and Sudarsky (2014b) we have disputed such an assertion by displaying an array of conceptual problems with the way the formalism is deployed in measurement situations.[1] In Griffiths (2015), however, arguments against our objections are presented, and so the main objective of this paper is to respond to such a challenge. We hope that, by doing so, we will not only be able to adequately defend our position, but also to shed light on the root of the disagreement. In this regard, we believe that the origin of the dispute arises from a difference on what CH proponents and we take the measurement problem to be, and, more importantly, on what CH proponents and we regard as a *satisfactory solution to the problem*. In short, we believe that such a solution must not only avoid making any reference to *measurements* or *cuts* at the fundamental level, but also that successful applications of the formalism must not depend on input not present in the fundamental theory. Our claim, in a nutshell, is that CH accomplishes the first but not the second.

In the rest of the paper we develop these ideas. To do so, we briefly review the CH formalism in Section 2 and in Section 3 we discuss what it takes to solve the measurement problem. Then, in Section 4 we summarize our arguments in Okon and Sudarsky (2014b) and in Section 5 we evaluate and respond to the challenges raised in Griffiths (2015). Finally, in Section 6 we present our conclusions.

2. A brief presentation of the Consistent Histories formalism

Before getting down to business, we will briefly describe the CH formalism (see Griffiths, 2002 for a comprehensive presentation). As we said above, CH assigns probabilities for all systems, microscopic or macroscopic, using the same machinery and without any reference to measurements or cuts. More specifically, the

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[1] Other objections against CH can be found in D'Espagnat (1987), Dowker & Kent (1996), Kent (1997, 2010), Barrett (1999), and Okon & Sudarsky (2014a).

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most general objective of CH is the prediction of probabilities for time histories of systems, where histories are defined as sequences of properties and are represented by projection operators at successive times. CH, then, introduces the notion of sets of histories and specifies rules that assign probabilities to the various elements of each set. However, according to CH, not all sets of histories allow for probabilities to be assigned. This is possible only when (i) the sum of probabilities of all members of a set equals one and (ii) all pairs of histories within the set are orthogonal. Families satisfying these two conditions are called *frameworks*, or *realms*.

A natural consequence of the CH formalism is that, given a system, multiple incompatible frameworks can be constructed (i. e., different frameworks that assign incompatible properties to the system). Therefore, in order to avoid inconsistencies, CH requires the imposition of the following rules:

- *Single-framework rule*: probabilistic reasoning is invalid unless it is carried out using a single framework.
- *Principle of liberty*: one can use whatever framework one chooses in order to describe a system.
- *Principle of equality*: all frameworks are equally acceptable in terms of fundamental quantum mechanics.
- *Principle of utility*: not all frameworks are equally useful in answering particular questions of physical interest.

This, however, comes with a price because the enforcement of these rules leads to the violation of the following principle:

- *Principle of unicity*: alternative descriptions of physical systems always can be combined into a single unified one, from which all views can be derived as partial characterizations.

Whether this is too high a price to pay is an interesting question. However, what we would like to point out for now is that, as we will see in Section 5, and contrary to what is claimed in Griffiths (2015), none of the objections that were presented in Okon and Sudarsky (2014b) are based on the fact that the Principle of unicity is not valid within CH.

3. Solving the measurement problem

A lot has been written about the measurement problem of quantum mechanics. A popular way to describe it, among many, is the following: even though quantum mechanics depends crucially on the notion of measurement, such notion is never formally defined within the theory. Then, in order to use quantum mechanics, one needs to know, *by means external to the theory*, what constitutes a measurement. Of course, the measurement problem is a problem of a theoretical framework and so, in order to state it, one needs to first specify in detail the theoretical framework in question.[2] This, given the proliferation of views regarding quantum mechanics, leads to a proliferation of ways to state the problem. For example, the description given above is suitable for Dirac's or von Neumann's formulation but does not apply to Bohr's, where the problem manifests as an ambiguity regarding where the classical-quantum cut should be drawn. It also does not apply to a formulation with a purely unitary evolution, where the problem manifests as a mismatch between experience and some predictions of the theory.

At any rate, for the purposes of this paper it is sufficient to note that both of us, and the author of Griffiths (2015), agree on the fact that the standard or orthodox interpretation suffers from the measurement problem (see e.g. Griffiths, 2002, p. 214). What we consider more important, given the objective of this work (i.e., evaluating whether CH solves or not the measurement problem), is a discussion of what constitutes a valid solution to the problem. In this regard, Griffiths (2015) offers the following:

> If quantum mechanics applies not only to the microscopic world of nuclei and atoms, but also to macroscopic objects and things that are even larger – from the quarks to the quasars – then the measurement process in which an earlier microscopic property is revealed in a macroscopic outcome should itself be describable, at least in principle, in fully quantum mechanical terms. Applied equally to the system being measured and to the macroscopic apparatus, and without the evasion and equivocation ridiculed by Bell (1990) (Griffiths, 2015, p. 3).

Namely, if quantum mechanics applies to everything – from quarks to quasars – then measurements must be fully describable in purely quantum terms. Of course, one could hold that quantum mechanics does not apply to everything, but in such a case one would need to clearly establish where to draw the line (i.e., where to insert the "Heisenberg cut") – something that no one has been able to achieve. In any case, the CH formalism assumes that quantum mechanics does apply to everything so we will stick to such a premise. The quote also mentions that the application of the quantum formalism to measurement scenarios must not involve "the evasion and equivocation ridiculed by Bell (1990)". So what does Bell (1990) say regarding a satisfactory quantum formalism (i.e., one that solves the measurement problem)? He concisely states the following:

> The theory should be fully formulated in mathematical terms, with nothing left to the discretion of the theoretical physicist (Bell, 1990, p. 33).

Then, according to Bell, there are two main components required by a valid solution for the measurement problem:

1. *The theory should be fully formulated in mathematical terms*: i.e., concepts such as *measurement*, *measuring apparatus*, *observer* or *macroscopic* should not be part of the fundamental language of the theory.
2. *Nothing should be left to the discretion of the theoretical physicist*: i.e., successful applications of the theory must not require any input not contained in the description of the situation at hand at the fundamental level.

The point, then, is that in order to solve the measurement problem it is not enough to construct a formalism fully written in precise terms. One must also make sure that successful applications of the formalism do not require the introduction of information that is not already contained in the fundamental description given by the theory of the situation one wants to consider. That is, once a complete quantum description of the measurement scenario is given, including the quantum state of the apparatus and the full Hamiltonian (and remember that we are assuming that, at least in principle, that is always possible because we are assuming that quantum mechanics applies to everything), then, with that information alone, one must be able to use the theory to make concrete predictions regarding the possible final outcomes of the experiment.

It is important to emphasize that the above mentioned restriction to introduce "further information not contained in the description at the fundamental level" does not preclude the full specification of the

[2] The formulations of the measurement problem developed in Maudlin (1995), instead of specifying in detail the theoretical framework to be dealt with, impose general restrictions that all satisfactory formulations must obey.