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Quantum theory as the most robust description of reproducible experiments

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HIGHLIGHTS

- It is shown that logical inference, that is, inductive reasoning, provides a rational explanation for the success of quantum theory.
- The Schrödinger equation is obtained through logical inference applied to robust experiments.
- The singlet and triplet states follow from logical inference applied to the Einstein–Podolsky–Rosen–Bohm experiment.
- Robustness also leads to the quantum theoretical description of the Stern–Gerlach experiment.

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ABSTRACT

It is shown that the basic equations of quantum theory can be obtained from a straightforward application of logical inference to experiments for which there is uncertainty about individual events and for which the frequencies of the observed events are robust with respect to small changes in the conditions under which the experiments are carried out.

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1. Introduction

Quantum theory has proven to be extraordinary powerful to describe a vast amount of very different experiments in (sub)-atomic, molecular and condensed matter physics, quantum optics and so on. Remarkably, after so many extremely successful practical applications, there are still hot debates about conceptual backgrounds of quantum theory, and attempts to clarify the success continue until now.

The success of quantum theory reminds us of an example of another very successful theory, namely classical thermodynamics. Einstein said: "Classical thermodynamics is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts" [1]. Can we say that we understand the reasons of this success from the point of view of a more fundamental theory? Strictly speaking, a rigorous derivation of, say, the second law of thermodynamics from classical (or quantum) mechanics is lacking and therefore the answer should be "no" but in practice this does not matter too much. Our belief in thermodynamics is not based on mathematical deduction but on its power to account for everyday experience.

It has been emphasized many times that our description of physical phenomena at some level of observation is essentially independent of our view of "underlying" levels [2]. In the present paper, we apply the same world view to nonrelativistic quantum theory. Adopting this view immediately distinguishes our line of thinking from approaches that assume an underlying ontology [3–7] or formulate quantum theory starting from various sets of axioms [8–36]. We start with something that is as reliable as one can imagine, which in our view, are the principles of logical inference [37–41] (a brief, formal introduction is given below) and ask the question: what should be added to these principles in order to derive, for instance, the (nonrelativistic) Schrödinger equation? The answer is that it suffices to add Bohr's correspondence principle in a probabilistic sense.

The present work explores the possibility of exploiting logical inference [37–41] that is inductive reasoning to give a rational explanation for the success of quantum theory as a description of a vast class of physical phenomena. We are not concerned with the various interpretations [19,42–44] of quantum theory.

We introduce the basic ideas of our approach by starting with a few quotes of Niels Bohr:

1. There is no quantum world. There is only an abstract physical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can *say* about nature [45].
2. Physics is to be regarded not so much as the study of something a priori given, but rather as the development of methods of ordering and surveying human experience. In this respect our task must be to account for such experience in a manner independent of individual subjective judgment and therefore objective in the sense that it can be unambiguously communicated in ordinary human language [46].
3. The physical content of quantum mechanics is exhausted by its power to formulate statistical laws governing observations under conditions specified in plain language [46].

The first two sentences of the first quote may be read as a suggestion to dispose of, in Mermin's words [47], the "bad habit" to take mathematical abstractions as the reality of the events (in the everyday sense of the word) that we experience through our senses. Although widely circulated, these sentences are reported by Petersen [45] and there is doubt that Bohr actually used this wording [48]. The last two sentences of the first quote and the second quote suggest that we should try to describe human experiences (confined to the realm of scientific inquiry) in a manner and language which is unambiguous and independent of the individual subjective judgment. Of course, the latter should not be construed to imply that the observed phenomena are independent of the choices made by the individual(s) in performing the scientific experiment [49].

The third quote suggests that quantum theory is a powerful language to describe a certain class of statistical experiments but remains vague about the properties of the class. Similar views were expressed by other fathers of quantum mechanics, e.g., Max Born and Wolfgang Pauli [50]. They can be summarized as "Quantum theory describes our *knowledge* of the atomic phenomena rather than the atomic phenomena themselves". Our aim is, in a sense, to replace the philosophical components of these statements by well-defined mathematical concepts and to carefully study their relevance for