Book Proposal
Dismantling Quantum Paradoxes

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Why This Book: The Big Picture

This will be a book about Quantum Mechanics intended for the professional philosopher and physicist. In the following, I will describe where this book is coming from, where it is going, and why I believe it is needed.

In my career, I have studied first physics and then philosophy. My intellectual journey made me realize how little physics (what physics is, what physics does, what physics says, what it means to do physics) is known in the philosophical community. And this is a scandal, especially if someone wants to do philosophy of physics or metaphysics (the broad study of what there is). Too often philosophers read and base their work on popular books. Scared of the technical details, to do their job they rely on the word of the physicist. This is understandable, given their different training. But the fact that it is understandable does not mean that it is right: in fact the physicist, in writing the expository book, provides an *interpretation* of the technical results. This fact seems both unavoidable and sensible: unavoidable because the purpose of a popular book is to explain the technical results to the non-experts (who, in virtue of being non-expert does not possess the required technical skills), and sensible because, it seems sensible to trust the experts. As a consequence, the philosopher does not (first of all because she cannot, and then because it seems unnecessary) question the basic assumptions made by the physicist who wrote the book. Most of the time there is no problem whatsoever with that: experts usually deserve their name, and therefore can be trusted. But in some other cases questioning the expert is exactly what the philosopher should do. In fact, the role of the philosopher is usually to fill-in the gap left open by the technician, reflect on whether the assumptions made are justified, worth-making or actually corresponding to what one wished to assume. This is especially true in the case of Quantum Mechanics (even if not exclusively), in which it is now recognized by many that there are substantial conceptual problems that cannot be left unsettled any longer.

My claim is that the philosopher of physics, and the metaphysician alike, cannot afford of being ignorant about the details of the physical theories she is discussing, because *the conceptual problems of Quantum Mechanics are rooted in such ignorance.* It is an unfortunate fact that a lot of the current philosophical debate is misguided because based on improper knowledge of the subject matter: a mistaken assumption can generate an endless list of false problems. This incredible waste of time and energy has to come to an end. Resources should be used differently, and this can be done by critically evaluation the different theories, once they are properly understood.

One might object that philosopher cannot really read technical stuff, it is just impractical: the philosopher has a different training, for one thing. So the philosopher *has* to read and rely on popular books, regardless on their weaknesses. It is probably true that it is impractical for the philosopher to read, say, a book on quantum field theory that is commonly used in physics courses. But this is just my point: *an accessible text that provides understanding of the different ingredients used in a theory, their mathematical representation, a sketch of the techniques used, an explicit statement of what the assumptions are and why they are made, and why they are sensible*, is not available yet. But that does not mean that one is not necessary: *one cannot do her job as a philosopher of physics or as metaphysician if she not fully aware of what the theory says and how it works.* And here is where I come in. My plan is to explain how mathematics is used to do physics: some mathematics is used to describe what there is (and therefore is relevant for metaphysics), some other is used to solve technical problems. This second one is philosophically irrelevant. So my project is to *strip away physics from the philosophically irrelevant mathematics and present it to the philosopher.* This is just a slogan, but expresses the bottom line clearly enough: certain technical details or mathematical relations need to be known by the philosopher in order to do her job, while some other details are just interesting technically or mathematically, but do not have much relevance to the foundational issues the philosopher is (should be) interested in, and therefore can be ignored.

One might think that my approach is at best a compromise, since the philosopher will have to "trust me" in my distinction between the foundationally relevant and irrelevant details. This is not exactly true: the book (like any other interesting book) will inevitably be *expressing and defending a point of view, mine.* But, in line of the best philosophical tradition, it will not an uncritical and dogmatic presentation: I will make every assumption explicit, I will provide replies to possible weaknesses of my view, I will compare my view with alternatives to it. Doing this is a step in the right direction, with the the of providing to the philosopher the tools necessary to judge for herself. *After reading this book the philosopher will be more aware of the relationship between mathematics and physics, and start from that knowledge to do the philosophical work.*

This is certainly an ambitious project. But it is what I have been doing in all my professional career, both as a physicist and as a philosopher. My goal has always been to understand if physics can tells us something about the world, and if it can, what does it tell us, with what limitations. Now I have reached some conclusions, and I would like to share them with everyone in a book, not for my own satisfaction but because they can be useful. Quantum Mechanics is a theory in which (for various reasons) there is much confusion. In fact, due to its intrinsic technical nature, it is extremely difficult for the non-expert to distinguish what is foundationally relevant or irrelevant. The theory uses a mathematics that is much more sophisticated and certainly less familiar than the one used in other theories, like Classical Mechanics. This has certainly been a huge obstacle to the understanding of the theory on the part of the non-expert, not to mention the possibility of criticizing what is assumed in the theory. To give an example, it is commonly said that the wave function is the mathematical entity that represents physical objects in Quantum Mechanics. This is an assumption. Is it a sensible assumption? Could someone assume something different? Why, why not? In almost the entirety of books on the subject (popular or technical, with few notable exceptions) this assumption is not even discussed. But why not? How do we know it is an "innocent" assumption? Most times, it is not even presented as an assumption. Rather, it is often said that the wave function *has* to represent physical objects. But where this "must" is coming from? Is it true that there is such a strong constraint?

The question is: *how the philosopher can answer these philosophical questions, if she is not confident with the technical details?* Indeed, I strongly believe (and can argue for the thesis) that all (and I really mean *all*) the conceptual problems of Quantum Mechanics, all the mysteries, the paradoxes, the oddities that are considered unavoidable consequences of living in a quantum world do disappear once we reflect on this very question: Why the wave function and not something else? What is different about the wave function? What are the consequences of that choice? Are they acceptable? Are the only alternatives? If we made a different choice, would these consequence go away?

Maybe quantum theory could be just the first of a series of similarly inspired books on the other fundamental physical theories we have, maybe not. For sure, though, it seems to me the perfect way to start: clear-up all the myths and legends about Quantum Mechanics based on mistaken assumptions done by the (technical) experts, and let the other (conceptual) experts do their job.

What is the Audience of this Book

This book aims to be a "popular-but-exactly" book on Quantum Mechanics, mainly aimed to the philosopher who really wants to do her job confidently and with competence. My target audience will therefore be the philosopher of science, philosopher of physics and the metaphysicians, may them be advanced graduate students or professionals. I also would put in the audience professionals in physics with an interest in foundational issues, and who wants to have more perspective on what she is doing: sometimes even the greatest scientists are "carried away" by the calculations and they forget where they were originally heading. This book could be extremely beneficial for their own work since it would make them re-gain perspective on their big picture, re-think and re-rank the different problems on a new light.

I do not consider this book a textbook, since it would also contain controversial philosophical reflections. In fact, after "clearing-up" Quantum Mechanics from all the obfuscating technical detail, I would necessary make some comments about the philosophical consequences of the results of such a clear-up. A typical example would be the one of operators. They have been connected with many puzzling features of Quantum Mechanics, like for example contextuality. Doing the aforementioned clear-up in this case would be to establish whether or not operator are fundamental or they are just a mathematical tool to describe experiments. The answer to this question will depend on what quantum theory one is considering (Copenhagen, Bohm , GRW, Many-Worlds...), and there will be different philosophical consequences. If operators *do* turn out to be fundamental, then it is true that properties are contextual (with all the consequences of that); if not, then properties are not contextual and all the debate turns out to be empty. In this sense, I will contribute with research, in addition to "technically popularize" Quantum Mechanics.

In any case, even if I do not primarily think to the book as mainly a textbook, it could be easily used as a textbook in a graduate seminar in philosophy of science, philosophy of physics or metaphysics. Usually no physics course is strictly required to philosophers (neither undergrad not grad), and this makes the case for a book like mine even stronger. Usually philosophers are introduced to physics in courses like philosophy of science, philosophy of science and/or metaphysics. One therefore could use the book as the main text or as a supplement (depending on the course one is teaching, and the particular attitude and style of the instructor). For example, faculty in the philosophy department happen to teach one semester graduate seminars just on Quantum Mechanics. In this case, my book could easily be the main text. In any case, most commonly there is more than one text per course, to give a broader perspective. In this case then it could also be used as an additional text in courses on the philosophy of physics (in which people usually discuss relativity, quantum and statistical mechanics), or in courses in metaphysics, especially in these departments that are science-oriented. It could even be more likely that this book could be used as a text in a philosophy of physics class if among the issues discussed in the course one has the nature of space and time, which happens more and more frequently.

A remark on my style: I find provocative titles engaging, and I believe that the advantage of being engaging surpasses the danger of being sometimes misleading or imprecise. In fact while the (maybe) intrinsic imprecision of a cool or catchy title can be cleared up in the text, the use of a boring but more precise title might result in a book that is never opened and enjoyed. Let me add that to write in a provocative way does not necessarily mean one is behaving unprofessionally. A typical example of that would be Richard Dawkins' "The Selfish Gene": he does not literally mean the gene *is* selfish, but the use of such metaphor makes the book even a more avid read.

What is New and Different in this Book

Books are expensive, and in this time of crisis one tends to be even more careful about the money she spends. So why spend on this, if there are so many others? Because there are not many others, mine is unique: while it is true that there are some notable books in the foundations of Quantum Mechanics, they have either a different target group, or a different focus, or a different overall goal. For example, my book would be different from D.Z. Albert's "Quantum Mechanics and Experience" or C.G. Ghirardi's "Sneaking at God's Cards" because it would be more technical, or from T. Maudlin's "Quantum Nonlolocality and Relativity" because it would have a different aim and a different scope. My book would also be different from D. Dürr's "Bohmian Mechanics" for the same reason and because it would be directed to a more philosophical audience. R. Penrose's "The Road to Reality" has a similar ambition, but unfortunately it fails in the chapter dedicated to Quantum Mechanics.

As far as the comparison with the physics textbooks (pick any!), mine would emphasize the foundation of the theory (as opposed to the mathematical techniques), the differences and the commonalities between the various fundamental quantum theories, the philosophical questions that the theory might raise and the possible responses.

The Book Outline

Here is a tentative outline of the book, with the description of what will be contained in the different parts, chapters and sections.

1 PART I: MATHEMATICS AND PHYSICS

In this part I plan to explain what is the subtle relation between mathematics and physics. This relation is less trivial than one might think it is at first, and not to appreciate the relation between the two disciplines has lead to very serious misunderstandings and pseudo-problems. To do this, I will analyze what a fundamental physical theory is, what it does, how it does it, and what it means to explain something with it.

1.1 Fundamental Physical Theories: Classical Mechanics

In order to clarify the relation between mathematics and physics I plan to use one of the clearest fundamental physical theories ever developed, namely Classical Mechanics. In this theory it is crystal clear what mathematical objects represent the physical entities the theory postulates existing, and why. Also, it is clear how the theory works: it postulates what exists, it assigns a mathematical variables to represent it, it postulates another (or more than one) to account for how it moves through space and time. If one understands how physics works here, she will clearly see what is going wrong in Quantum Mechanics, as I will argue. I will articulate this chapter in different sections:

1.1.1 The Apple and Other Stories

I will discuss first the empirical input that drove the development of the theory (the so-called "empirical stage").

1.1.2 The Three Musketeers

(They would be Newton, Lagrange and Hamilton.) Here I will consider the theoretical stage of the theory, in which the formalization was established. The next step will be to "interpret" such formalism. I will emphasize that a certain formalization (the Newtonian one) are more fundamental than others (the Lagrangian and the Hamiltonian formulations), which in fact were driven by the need to solve technical difficulties.

1.1.3 The Devil is in the Details

This will be a section to describe how the situation changed when electromagnetic phenomena were discovered.

1.1.4 "Let us Assume the Cow is a Sphere..."

In this section the focus will be on the role of symmetries in the theory: it has been claimed by many that they are important, but it is unclear exactly why is that, so I will clarify that.

1.2 Explanation in Physics: Statistical Mechanics

In this chapter I plan to discuss what kind of explanation we can have in physics, and in order to make my point I will use Statistical Mechanics as an example.

1.2.1 The Word is Boring

Reductionists claim that everything is fundamentally made of the entities that physics postulates, and that the rest can be "accounted for". Statistical Mechanics is the best example to explain how this is supposed to go.

1.2.2 It Is not My Fault if My Room is an Increasing Mess

In this section I will discuss what needs to be explained by physics in this context. Therefore, I will explain the laws of thermodynamics, in particular the second law, to show how the macroscopic world seems to be in contrast with a microscopic Newtonian world governed by reversible laws.

1.2.3 The Needle in the Haystack

Here I will present Boltzmann's statistical explanation of thermodynamics, and what problems are left open (the initial condition improbable state).

1.3 First Steps Away from the Classical World: Quantum Mechanics

One of my main claims will be that there should not be any fundamental difference between the way in which the theory works classically and quantistically. In this chapter the parallel between Classical and Quantum theory begins: I plan to discuss the "empirical stage" of Quantum mechanics first, and the "theoretical stage" after. The discussion of the theoretical stage will be mostly historical, while the actual comparison with Classical Mechanics is instead left for the next part. Here is a more detailed articulation of this chapter into sections:

1.3.1 Four Men Entered in a Coffee Shop...

The fundamental experiments that originally motivated the development of a new theory are here presented and explained: Plank, Bohr, deBroglie, Stern and Gerlach, Young, to name some. (The men in the title are Schrödinger, Heisenberg, Bohr and Von Neumann)

1.3.2 ... and They Came out with a Linear Operator

This section will start discussing the first proposed formalizations of quantum theory (the one by Schrödinger, and the other by Heisenberg) to arrive to the axiomatization due to Von Neumann. Many questions will be answered in this section, among which the following: How did these formalization came about? How are they different from one another? What is the meaning of the axiomatization and the assumptions made therein? New mathematical entities are introduced, most notably the wave function and linear operators to deal with the new discoveries. What are they, and why are they needed? More interesting questions (like: what is their role in the theory? Why them and not something else?) will be left for later chapters (mostly for strategic reasons). (The joke in the title is that the men went to the coffee shop to eat something, and somehow they came out with some funny non-edible thing...).

1.3.3 Space Wars

In this section I will present and discuss the variety of spaces that are used in Quantum Mechanics: Hilbert, Configuration, Phase, and Tensor Spaces. The questions will be: which one represents physical space?

1.3.4 "In This World it is Forbidden to Be Local!"

In this section I will present a crucial and unique feature of Quantum Mechanics, namely nonlocality.

1.3.5 Are Cows still Spheres?

The main question here will be: How does the discussion about symmetries change in this context?

2 PART II: PHYSICS AND METAPHYSICS

This part is the one in which one uses the information presented in the previous part and use it to critically evaluate the status of Quantum Mechanics as a fundamental physical theory. It will be articulated in different chapters, as follows.

2.1 Theories and Explanations: The Quantum Problems and the Quantum Solutions

In this chapter I plan to present the reasons why Quantum Mechanics is, as such, an unsatisfactory scientific theory. I will discuss the main problems of quantum mechanics, principally the measurement problem, and its proposed solutions. Then I will discuss: what are the consequences of such solutions? Are they equally good (or bad)? Why in Classical Mechanics we are not in such trouble? I will divide this chapter in the following sections:

2.1.1 Quantum Horror Stories

Here I will analyze the reasons why Quantum Mechanics is puzzling: the measurement problem will be discussed.

2.1.2 Quantum Bed-Time Stories

I will present here the first solutions to the measurement problem, among which the one provided by Bohr, the one of Von Neumann, the one of deBroglie and Bohm, the one of Everett, the one of Ghirardi, Rimini and Weber.

2.1.3 Man-Made World?

Here I will critically compare the different solutions discussed above, that will be divided into Quantum Theories with and without the observer. I will analyze the different consequences of bringing the observer in the theory or leaving her out. I will argue that she should be left out. Having done that, only few Quantum Theories will be left on the table: Bohmian Mechanics, the GRW theory, and the Many-Worlds theory.

2.2 Quantum Theories Without Observer: the Metaphysics

Finally, this will be the chapter of most philosophical interest, in which we will see what Quantum Mechanics tells us about the world, and how it does that. In fact I plan to explain here how one should read the mathematics of the different Quantum Theories to make claims about the nature of reality (the metaphysics). The first three sectons will be devoted to describe the metaphysics of the main Quantum Theories without observers described in the previous chapter:

2.2.1 Leave the Cat Alone

I will claim here, contrary to most books (including most of the ones that I regard to be the best discussions of the subject, as Albert, Ghirardi, and Maudlin), that thinking about the Schrödinger cat can be very misleading, and I will present what my take on the subject is. Namely, I think what is to blame is the assumption that very few ever seriously put into doubt. That is, the troubles come from insisting that the wave function represents physical objects. I will recall what it means to use mathematics to do physics, and what it means for a physical theory to be (scientifically) explanatory, especially in connection with the question of what space is physical space. Once these things are done, I will argue what the natural way of reading the formalism should be.

2.2.2 Follow the Trail

First the picture of reality described by Bohmian mechanics will be presented.

2.2.3 A Leap in the Dark

Then it will be the turn of the GRW theory.

2.2.4 Multiplicity

Last but not least it will be the turn of the Many-Worlds theory.

2.3 Nature of Fundamental Physical Theories

In this last chapter I will summarize the main claims: Quantum Weirdness is just a product of the fact that one did not reflect enough on what a fundamental physical theory is, what it does, and how it is supposed to do it.

2.3.1 Curiosity did not Kill the Cat

I will here challenge the claims (by Kuhn and others) that there is such a thing such the quantum revolution: there is none. Quantum Mechanics, if properly understood, is fundamentally just a theory like Classical Mechanics was, but with different laws, that have different consequences.

2.3.2 A Giant Leap for Mankind

I will discuss what to do from here: now that we have "made sense" of Quantum Mechanics, what are the consequences for the reconciliation of this theory with Relativity?