Preface

Fifty years ago—in 1963, to be precise—the British physicist Trevor Marshall published a paper in the *Proceedings of the Royal Society* under the short title *Random Electrodynamics*—an intriguing title, at that time. To date this paper has received just over four citations per year, which means it is alive, but not as present as it could be, considering the perspectives it opened for theoretical physics. Shortly thereafter a related paper was published by a young US physicist, Timothy Boyer, under the longer title *Quantum Electromagnetic Zero-Point Energy and Retarded Dispersion Forces.* Boyer does not cite Marshall's paper (although he does so in his third paper, which is followed by a productive 50-year long work in solitary), but instead he refers to the work of David Kershaw and Edward Nelson on stochastic quantum mechanics. All these papers share a central feature: they are based on conceiving quantum mechanics as a stochastic process. Marshall mentions explicitly the existence of a real, space-filling radiation zero-point field as the source of stochasticity. Boyer sees a deep truth in this, and in a note added to his manuscript he comments that "…in this sense, quantum motions are experimental evidence for zero-point radiation."

From a historical perspective, we recall that nearly 50 years earlier—in 1916, to be precise—Nernst had proposed to consider atomic stability as experimental evidence for Planck's recently discovered zero-point radiation. This visionary idea was largely ignored by the founders of quantum mechanics, the only (brief) exception being the Einstein and Stern paper of 1913; such is history. Both Marshall and Boyer succeed in demonstrating that some quantum phenomena can indeed be understood by the simple expedient of adding this random zero-point field to the corresponding classical description. Their pioneering work was soon followed by that of other colleagues, moved by the conviction that the random zero-point field has something important to tell us about quantum mechanics. Many other results have been obtained during this period, which constitute the essence of the theory largely known under the name of *stochastic electrodynamics*. At the same time, other researchers, notably Nelson, dedicated their efforts to develop the phenomenological stochastic theory of quantum mechanics. The perception that quantumness and stochasticity are but two different aspects of a reality, started to gain support from several sides.

So here we are, 50 years later. In the mean time, quantum mechanics has continued to develop; the new applications derived from it only serve to reaffirm it as a powerful theory. Along with its success, however, comes an increasing recognition that its old foundational problems have not found convincing solution. Recall the birth of quantum theory: Bohr's model of the hydrogen atom was supported on a postulate that implied a fundamental violation of electrodynamics. Truly, such postulate was necessary at its moment, but urgent necessity does not restore physical consistency. Then came the mysterious matrix mechanics, and the no less mysterious de Broglie wavelength. Such obscure premises served as foundations for the interpretative apparatus of quantum theory. And obscurity and vagueness followed, along with a formidable mathematical apparatus. From this perspective, one easily concludes that better supporting and supported principles are required. More recent efforts from a number of authors attest to the conviction that quantum mechanics, and more generally quantum theory, is in need of an alternative that helps to explain the underlying physics and to solve the conundrums that have puzzled many a physicist, from de Broglie and Schrödinger to Einstein and Bell, among many others. Common to most of the recent efforts in search of an alternative is precisely the idea that the quantum description emerges from a deeper level.

Quantum mechanics constitutes usually both, the point of departure and the final reference, for all inquiries about the meaning of the theory itself. Its conceptual problems are therefore looked at from inside, which provides limited space for rationalization, and even in some instances creates a kind of circular reasoning of scant utility, as is amply testified by the unending discussions on these matters. Experience evinces that an external and wider approach is indeed required to grasp the meaning of quantum theory and get a clear, physically understandable, and preferably objective, realistic, causal, local picture of the portion of the world that it scrutinizes.

The main purpose of this book is to show that such alternative exists, and that it is tightly linked to the stochastic zero-point radiation field. This is a fluctuating field, solution of the classical Maxwell equations, yet by having a nonzero mean energy at zero temperature it is foreign to classical physics. The fundamental hypothesis of the theory here developed is that any material system is an open system permanently shaken by this field; the ensuing interaction turns out to be ultimately responsible for quantization. In other words, rather than being an intrinsic property of matter and the (photonic) radiation field, quantization emerges from a deeper stochastic process. A physically coherent way to understand quantum mechanics and go beyond it is thus offered, confirming the notion of emergence—the coming forth of properties of a compound system, which no one of its parts possesses.

The theory here presented has been developed along the years in an effort to find answers to some of the most relevant conceptual puzzles of quantum mechanics, by providing a physical foundation for it. It is thus not one more interpretation of quantum mechanics, but constitutes a comprehensive and self-consistent theoretical framework, based on well-defined first principles in line with a realistic viewpoint of Nature. There is neither the opportunity nor the need to resort to ad hoc tenets or philosophical considerations, to assign physical meaning to the elements of the theory and interpret its results.

As the formalism of quantum mechanics is successfully reproduced, some may argue about the value of redoing what is already well known. However, the usual theory, with its interpretations included, seems to tell us more about our knowledge and our way of thinking about Nature, than about Nature itself. A good part of what really happens out there remains hidden, waiting to be disclosed. With this volume, our intention is to contribute to this disclosure and to share the fascinating experience of discovering some of the quantum mysteries and intricacies along the process. Moreover, a door is opened to further explorations that may unravel new physics. As the reader will appreciate, this chapter is not closed; there is much that remains unexamined, awaiting future investigations.

This book has been prepared for an audience that is conversant with at least the most basic ideas and results of quantum mechanics. More specifically, it is intended to address those readers who (either secretly or openly) seek a remedy to the apocalyptic statement by Feynman, that "nobody understands quantum mechanics." Its contents should be of value to researchers, graduate students and teachers of theoretical, mathematical and experimental physics, quantum chemistry, foundations and philosophy of physics, as well as other scholars interested in the foundations of modern physics.

Throughout this volume, frequent reference is made to *The Quantum Dice. An Introduction to Stochastic Electrodynamics* (*The Dice*), a precursor containing many ideas and results that have survived the test of time and others that have been superseded or improved here. *The Dice* and the present book differ in at least two central aspects. First, the version of stochastic electrodynamics discussed in the former was essentially limited to linear problems and failed to properly address the more general nonlinear case; this limitation is successfully lifted in the present book. Secondly, in addition to applying the Fokker-Planck method (already contained in *The Dice*) with success, particularly in Chaps. 4 and 6, new procedures are developed and crucial physical demands (as e.g., the balance of energy, and ergocidity) are identified, which converge into a theoretical framework that is clearer, richer and more unified than the former one. Further to facilitating a smooth and fruitful incursion into the territories of quantum mechanics and quantum electrodynamics, the new developments result in an expansion of the aims of the theory, for example by including the study of composite systems or by opening the door to future analysis of the system before the attainment of the quantum regime.

In addition to the bibliography at the end of the chapters, a list of suggested references (not cited in the chapters) appears at the end of the volume. In the bibliography, the items marked * refer to stochastic electrodynamics (some of them including stochastic optics) and those marked ** are general or topical reviews on stochastic electrodynamics; papers marked ‡ are overtly critical about stochastic (quantum) mechanics; those marked ‡‡ contribute to the development of that theory, but may express some important criticism about it. Some few abbreviations are used in the text, all of them easy to spell out: QM, QED, SED, LSED, ZPF, FPE, GFPE for quantum mechanics, quantum electrodynamics, stochastic electrodynamics, linear stochastic electrodynamics, zero-point field, Fokker-Planck equation, and generalized Fokker-Planck equation, respectively. In Chap. 1—and occasionally elsewhere—CI and EI are used for the Copenhagen and ensemble interpretations of quantum mechanics, respectively.

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