

Preface

Recent progress in science and technology has led to the revival of an old question concerning the relevance of quantum effects in biological systems. Indeed Pascual Jordan's 1943 book, *Die Physik und das Geheimnis des Lebens* had already posed the question "Sind die Gesetze der Atomphysik und Quantenphysik für die Lebensvorgänge von wesentlicher Bedeutung?" (Are the laws of atomic and quantum physics of essential importance for life?) and coined the term Quanten-Biologie (quantum biology). At the time this question was essentially of a theoretical nature as the technology did not yet exist to pursue it in experiment.

Indeed quantum biology has been benefiting considerably from the refinement in experimental tools which is beginning to provide direct access to the observation of quantum dynamics in biological systems. Indeed, we are increasingly gaining sensitivity towards quantum phenomena at short lengths and timescales. In recent years, these newly found technological capabilities have helped to elevate the study of quantum biology from a mainly theoretical endeavour to a field in which theoretical questions, concepts and hypotheses may be tested experimentally and thus verified or disproved. We should stress here that experiments are essential to verify theoretical models because biological systems already have a complexity and structural variety that prevents us from knowing and controlling all of the aspects. Results obtained using these refined experimental techniques lead to new theoretical challenges and thus stimulate the development of novel theoretical approaches. It is this mutually beneficial interplay between experiment and theory that promises accelerated developments within the field.

Biological systems tend to be warm, wet and noisy (the latter because they are exposed to environmental fluctuations), conditions which are normally expected to result in rapid decoherence and thus suppression of quantum features. Therefore quantum phenomena may at first sight seem to be unlikely to play a significant role in biology. Note, however, that at the level of molecular complexes and proteins, important biological processes can be very fast (taking place within picoseconds)

and well localised (extending across a few nanometres, the size of proteins) and may thus exhibit quantum phenomena before the environment has had an opportunity to destroy them. Hence the possible existence of significant quantum dynamics is a question of length and timescale; indeed quantum phenomena such as electron tunneling have been observed in biological systems and there is some evidence for proton tunneling in enzymes. As such, tunneling phenomena are not intimately related to biology and the question therefore remains whether on the one hand biological systems will exhibit more complex quantum-dynamical phenomena that may either involve several interacting particles or multiple interacting components of a network, or on the other hand whether the specifics of the biological systems and their environments will play a crucial role in allowing or supporting certain quantum-dynamical phenomena in biology. Only then could we call these 'non-trivial' quantum effects in biological systems. Indeed, it appears that there are biological processes such as energy and electron transfer in photosynthesis, magneto-reception in birds or the olfactory sense that rely at a fundamental level on such 'non-trivial' quantum-dynamical processes. Thus quantum effects in biology may well be possible and more importantly relevant towards function.

This book reports on quantum biology, its theoretical foundations, experimental findings and future possibilities as they have emerged over the past few years. Needless to say not all subjects can be covered and we have had to make a sub-selection that has been driven by several objectives. Firstly, given that the basis of the field is the fruitful interplay between experiment and theory, we have endeavoured to choose subjects that are either already under experimental investigation or for which it could be expected that technology will give access to these theoretical predictions in the foreseeable future. This has led us to exclude subjects such as quantum consciousness or the speculations concerning the origin of life. Secondly, it is our aim to provide a reasonably coherent set of chapters, starting from experimental and theoretical foundations and leading on to specific topics of interest. Finally, of course, personal preferences and tastes do also play a role.

The original plan for this book was hatched during the first conference on Quantum Effects in Biological Systems (QuEBS 2009), held from 7–10 July, 2009 in Lisbon, Portugal, which has become the first of the annual QuEBS conferences. Subsequent QuEBS meetings were held at Harvard University in 2010, Ulm University in 2011, Berkeley in 2012 and Vienna in 2013, and their ever growing attendance attests to a growing interest in the field.

This steady development has convinced us that the time is right for an introductory book on quantum effects in biology and we do hope that the present text will help scientists, especially young and adventurous scientists, during or shortly after their PhD, to gain a first insight into the field of quantum biology. It is our hope

that in this way we can assist the further development of the field by converting an increasing number of scientists into becoming quantum biologists.

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