Coherent Evolution in Noisy Environments

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ISBN 978 3 540 44354 4
Format (B x L): 15,5 x 23,5 cm
Gewicht: 1380 g

Weitere Fachgebiete > Physik, Astronomie > Angewandte Physik > Statistische Physik, Dynamische Systeme

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Preface

‘Coherent Evolution in Noisy Environments’ was the title of an international school at the Max-Planck-Institute for the Physics of Complex Systems in Dresden, Germany, from 2 April to 30 May 2001. Yet, this is also the general theme which a growing community of physicists is contemplating as it comes to monitor, guide, or even control the time evolution of isolated quantum systems. The latter can never be perfectly isolated (be it for the purpose of observation) from their environment – which is noisy (since never under complete control) – and will therefore exhibit traces of this, possibly residual, coupling on sufficiently long time scales. However, it is precisely the coherent nature of its time evolution which makes an isolated system quantum, and it is the detrimental influence of dissipation and of noise fed into the system from the environment, which induces decoherence as time evolves.

Given the last two decades’ extraordinary progress in the experimental art of isolating single quantum objects (which Schrödinger could only think about in a, by now, famous thought experiment), the theoretical understanding of (de-)coherence and its implications has re-emerged as an important issue of fundamental relevance. Feynman’s remarks on the simulation of complex quantum evolution using quantum systems appears to become a more realistic enterprise; moreover quantum cryptography, communication, and computation are identified as emerging key technologies of our young century. If these fields shall guarantee some shareholder value on the long run, our theoretical understanding of the coherent evolution of quantum systems in the presence of noise, and, hence, of decoherence, needs a considerable sharpening.

Many and rather distinct subdisciplines of physics and mathematics have their word to say in this context. Whilst quantum opticians arguably come up with the cleanest experimental conditions – which allow for a highly reductionist approach to the quantum world – the condensed matter and mesoscopics communities have to fight with an abundance of imperfections which invites strong input from statistical physics. With some reason one might say that the former can tell us a little more about coherence (and controlled decoherence), whereas the latter are closer to a general theory of decoherence with less stringent simplifications. Nonetheless, both communities are expected to intensify their communication – given the recent realization of simple models of solid state transport theory in quantum optical experiments. Finally, the novel point of view of quantum information theory provides a general framework for coherence, decoherence, and
quantum information processing in quantum cryptography, communication, and
computation, and receives input from mathematical physics as well as from pure
mathematics.

It was the purpose of the school at the MPI-PKS in Dresden to make these
different communities listen (and speak) to each other, to convey their differ-
ent languages, distinct methodologies, and different key challenges to the young
and eager in these different fields. If we were able to reach this aim, at least
partially, this was the merit of the lecturers of this school. Each of them enthusi-
astically took on the burden of preparing and delivering between 6 and 10 hours
of lectures, sometimes gave additional sessions, and actively participated in the
students’ seminars and informal discussions, as well as in the other lecturers’
courses. Therefore, we should like to thank Hans Briegel, Berge Englert, Gert
Ingold, Burkhard Kümmerer, Panagagiotis Lambropoulos, Mark Raizen, Wal-
ter Strunz, Steven van Enk, Harald Weinfurter, and Kurt Wiesenfeld, for their
crucial contributions to this school.

Towards the end of the event, some of us agreed that the lectures should be
conserved, and this idea was strongly encouraged by the two co-organizers of the
school, Reinhard Werner and Anton Zeilinger, whom we are very much indebted
to for their constructive support in all respects. The result is this present book,
which contains a good part of the school lectures, and an additional contribu-
tion by Keyl and Werner. It starts out with Ingold’s outline of a rather general
quantum treatment of dissipation – reflecting the point of view widely spread
in the condensed matter and mesoscopies community. Then, Englert and Morigi
give a detailed outline of the algebraic treatment of dissipation in the (possibly
periodically driven) damped harmonic oscillator, an open quantum system of
paradigmatic importance in quantum optics. With the micro-maser as its exper-
imental realization in mind, these lectures constitute – in some respect – the seed
for the subsequent chapters by Wiesenfeld et al. and Kümmerer. Both of them
deal with stochastic processes, though in rather orthogonal languages, and within
rather different contexts. Wiesenfeld et al. discuss the potentially constructive
role of noise in classical and quantum systems in the presence of some non-
linearity, whilst Kümmerer spells out the mathematical framework of quantum
Markov processes. Kümmerer’s lecture also provides the general mathematical
background of a good part of quantum information theory, and of the corre-
sponding treatment of decoherence as the small system’s entanglement with the
environment. This latter point of view is elaborated on in Strunz’s lecture, which
– through the discussion of an experimental realization in the Paris micro-maser
setting – is somewhat entangled with the contribution of Englert and Morigi,
and rephrases aspects of quantum stochastic calculus already touched upon by
Kümmerer. Strunz’ treatment of decoherence in phase space is complemented
by Aschauer and Briegel, who directly address decoherence in the context of
quantum communication, and notably its detrimental influence on quantum en-
tanglement. In particular, they develop efficient strategies to counteract decoher-
ence through the controlled disentanglement of the (quantum) carrier from the
environment. Finally, again in a more mathematical language, Keyl and Werner
show how quantum data can be protected against decoherence when sent through noisy quantum channels. They also come up with quantitative bounds on the tolerable error rate for such strategies to work.

We believe that this collection of contributions from quite distinct areas nicely illustrates how those areas are slowly getting closer – propelled by some progresses made in physics and mathematics during the last couple of decades – and that we witness how a common language emerges in this exciting area of fundamental research.

Let us finally express our gratitude to all those who made possible the school, and as a direct product thereof this book, through their support and concrete efforts behind the scene: Claudia Poenisch, Christian Caron, Helmut Deggelmann, Torsten Goerke, Heidi Naether, Christa and Klaus Quedenbaum, Andreas Schneider, Hubert Scherrer, Andreas Wagner, Jan-Michael Rost, and the Max-Planck Society.

Dresden and Wien, August 2002

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