

Preface

Entanglement and (de-)coherence arguably define the central issues of concern in present day quantum information theory. In state-of-the-art experiments, ever larger numbers of quantum particles are entangled in a controlled way, and ever heavier particles are brought to interfere. Some sub-fields of quantum information science, in particular quantum cryptography, already find commercial applications, and communal communication networks that rely on quantum information technology are in preparation, as well as satellite-based quantum communication. Moreover, entanglement is no more considered as just an important resource for quantum information processing, but it allows for a better characterization of “complex” quantum systems, realized, e.g., in engineered, interacting many-particle systems, as well as in the solid state. Thus, there is a permanent and in many respects enhanced need for a deeper understanding of – and fresh approaches to – quantum entanglement, notably in high-dimensional quantum systems. Equally so, entanglement being a consequence of the quantum mechanical superposition principle for composite systems, we need a better understanding of the environment-induced destruction of coherent superposition states and of those interference phenomena that may survive the action of a noisy environment. Such research will allow us to identify realistic scales and possibly novel strategies for harvesting quantum interference phenomena.

The present book collects a series of advanced lectures on the theoretical foundations of this active research field and illustrates the breadth of present day theoretical efforts – from mathematics to mesoscopic transport theory. Uhlmann and Crell start out with a mathematical introduction to the geometry of state space, followed by an elementary introduction to entanglement theory by Mintert et al. Back again in the mathematical realm, Kauffman and Lomonaco discuss topological aspects of quantum computation, with some close relation to the theory of braids and knots. Ozorio de Almeida sheds new light on entanglement, in phase space, and touches some issues related to decoherence theory, which are then systematically expanded by Hornberger. Müller is subsequently concerned with dephasing and decoherence in the context of spintronics and disordered systems, thus establishing the bridge to real-life quantum transport, and the solid state.

All lecture notes start out from an elementary level and proceed along a steep learning curve, what makes the material equally suitable for student

seminars on the more fundamental theoretical aspects of quantum information, as well as to supplement advanced lectures on this topic.

The material assembled here was first taught by the authors during an international summer school on “Quantum Information” at the Max Planck Institute for the Physics of Complex Systems in Dresden, in September 2005, thus inspiring the idea to compile the present book. The editors’ special thanks therefore go to the authors, as well to Markus Grassl, Martin Rötteler, Christian Roos, Hartmut Häffner, Herbert Wagner, Per Delsing, Daniel Estève, Steffen Glaser, Gilles Nogues, Mauro d’Ariano, Robin Hudson, Reinhard Werner, Maciej Lewenstein, Andrzej Kossakowski, Karol Życzkowski, Mark Fannes, Richard Gill, Rainer Blatt, Marita Schneider, Christian Caron, Gabriele Hakuba, Andreas Erdmann, Helmut Deggelmann, Torsten Goerke, Heidi Naether, Andreas Schneider, Hubert Scherrer, Andreas Wagner, Karsten Batzke, and Jan-Michael Rost, who all have their share in getting the present volume into press.

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Foundations and Modern Trends

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