Q 7: Quantum Information: Concepts and Methods 1

Time: Monday 10:30–13:00 Location: SCH A118

Q 7.1 Mon 10:30 SCH A118

Verifying W-entanglement — •Hermann Kampermann[1], Otfried Gühne[2], Colin Wilmott[1], and Dagmar Bruss[1] — [1]Theoretische Physik III, Universität Düsseldorf — [2]Fachbereich Physik, Universität Siegen

We present a simple algorithm for finding specific decompositions of mixed density operators. The pure states in such decompositions belong to the same SLOCC entanglement class. This procedure can help to prove separability or to characterize specific types of entanglement. We use this algorithm to verify for some three qubit states W-type entanglement, i.e. states which can be written as a convex combination of pure W-states and which are genuine multipartite entangled.

Q 7.2 Mon 10:45 SCH A118

Linking a distance measure of entanglement to its convex roof — •Alexander Streltsov, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Institut für Theoretische Physik III, D-40225 Düsseldorf

An important problem in quantum information theory is the quantification of entanglement in multipartite mixed quantum states. We establish a new connection between the geometric measure of entanglement and a distance measure of entanglement. A direct application of our result provides a closed expression for the Bures measure of entanglement of two qubits. We also prove that the number of elements in an optimal decomposition with respect to the geometric measure of entanglement is bounded from above by the Caratheodory bound, and we find necessary conditions for the structure of an optimal decomposition. Further we present a new algorithm for an upper bound of the geometric measure of entanglement. See also arXiv:1006.3077 [quant-ph]

Q 7.3 Mon 11:00 SCH A118

Evolution equation of entanglement for multi-qubit systems — •Michael Siomau[1,2] and Stephan Fritzsche[3,4] — [1]Max-Planck-Institut fuer Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — [2]Physikalisches Institut, Heidelberg Universitaet, D-69120 Heidelberg, Germany — [3]Department of Physical Sciences, P.O.Box 3000, Fin-90014 University of Oulu, Finland — [4]GSI Helmholtzzentrum fuer Schwerionenforschung, D-64291 Darmstadt, Germany

Typically, the time evolution of entanglement of a system is deduced from studying its state evolution under the influence of decoherence. Instead of making explicit use of the state evolution for the analysis of the entanglement dynamics of a given system, Konrad et al. [1] recently derived an evolution equation of entanglement for a two-qubit system that provides a direct relationship between the initial and the final entanglement of the system when one of its qubits is subjected to an arbitrary noise. We have extended this concept towards multi-qubit systems under the same assumption that just one of the qubits undergoes the action of a noisy channel. In this contribution, we suggest and discuss an evolution equation of entanglement for a lower bound for multi-qubit concurrence [2].

[1] T.Konrad et al., Nature Phys. 4, 99 (2008).
[2] M.Siomau and S.Fritzsche, arXiv:1011.5348v1.

Q 7.4 Mon 11:15 SCH A118

Multi-partite entanglement in a driven qubit network — •Simeon Sauer[1], Florian Mintert[1,2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, D-79104 Freiburg, Germany

As demonstrated recently [1,2], periodic driving of a composite quantum system can induce entanglement that significantly exceeds the threshold of the static case. Alike general resonance phenomena this enhancement of entanglement occurs for very specific amplitudes and frequencies of the driving fields.

We aim to develop a general understanding of the underlying mechanisms. To this end, we consider a multi-partite quantum system that consists of several weakly coupled spins and study the interplay of periodic driving and multi-partite entanglement within the Floquet picture; *i.e.* we identify the dressed states of the driven system and quantify their entanglement by means of a multi-partite entanglement measure. Indeed, at well-defined values of the driving frequency and amplitude, we find a resonant behavior of entanglement. The occurrence of these resonances can be understood in terms of the single particle Floquet spectra only, what permits to predict resonances without solving the underlying many-body problem.

[1] Galve *et al.*, Phys. Rev. A 79, 032332 (2009).
[2] Cai *et al.*, Phys. Rev. E 82, 021921 (2010).

Q 7.5 Mon 11:30 SCH A118

Quantification of entanglement and polynomial invariants of homogeneous degree 4 — Christopher Eltschka[1], Thierry Bastin[2], Andreas Osterloh[3], and •Jens Siewert[4,5] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Institut de Physique Nucléaire, atomique et de Spectrosopie, Université de Liège, 4000 Liège, Belgium — [3]Fakultät für Physik, Universität Duisburg-Essen, 47048 Duisburg, Germany — [4]Departamento de Química Física, Universidad del País Vasco, 48080 Bilbao, Spain — [5]Ikerbasque, Basque Foundation for Science, 48011 Bilbao, Spain

The N-tangle of Wong and Christensen [1] (which for $N = 3$ is the three-tangle) gives the simplest $SL(2, C)^{\otimes N}$-invariant polynomial of homogeneous degree 4. The relevance of degree-4 polynomials for entanglement classification and quantification is increasing with the possibility of polynomial SLOCC classifications [2]. Extending a well-known theorem [3] we prove that all such polynomials naturally lead to degree-4 entanglement monotones. By focusing on four qubits we show how various degree-4 polynomial invariants introduced by different authors can be put into a common framework. Surprisingly, the invariants defined by Luque and Thibon [4] have a precise physical meaning, and have generalizations to multi-qubit and even multi-qudit systems.

[1] A. Wong and N. Christensen, Phys. Rev. A **63**, 044301 (2001).
[2] O. Viehmann, C. Eltschka, and J. Siewert, unpublished.
[3] F. Verstraete *et al.*, Phys. Rev. A **68**, 012103 (2003).
[4] J.-G. Luque and J.-Y. Thibon, Phys. Rev. A **67**, 042303 (2003).

Q 7.6 Mon 11:45 SCH A118

Maximizing entanglement with numerically optimized pulse design — •Fabian Bohnet-Waldraff[1], Florian Mintert[2], Uwe Sanders[3], Steffen Glaser[3], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg — [3]Department of Chemistry, Technical University of Munich, D-85747 Garching

The design of optimal pulse shapes, e.g. by means of the GRAPE algorithm [1], permits the accurate preparation of general quantum states. On the other hand, there are vital advantages in optimizing entanglement itself (as quantified, e.g. by a suitable entanglement measure) [2] rather than the fidelity with respect to a given entangled state. Like most techniques from optimal control theory, the GRAPE algorithm has been designed to target a specific state and, therefore, is not necessarily applicable to an entanglement measure as a target functional, since such measures are not maximized by a unique state. We discuss how GRAPE can be extended accordingly such that it permits the optimization of many-body entanglement in noisy environments. As a specific situation we apply this framework to nitrogen vacancy centers in diamond.

[1] N. Khaneja, T. Reiss, C. Kehlet, T. Schulte-Herbrüggen, S. J. Glaser, J. Magn. Reson. **172**, 296-305 (2005).
[2] F. Platzer, F. Mintert, A. Buchleitner, PRL **105**, 020501 (2010).

Q 7.7 Mon 12:00 SCH A118

On Hybrid Entanglement — •Karsten Kreis[1,2] and Peter van Loock[1,2] — [1]OQI, MPL, Erlangen, Germany — [2]Institute of Theoretical Physics I, Uni Erlangen-Nuremberg, Erlangen, Germany

In this talk, we define hybrid entanglement as entanglement between a discrete-variable quantum system and an infinite-dimensional, continuous-variable quantum system. A classification scheme is given leading to a distinction between pure hybrid entangled states, mixed hybrid entangled states (those effectively supported by an overall finite-dimensional Hilbert space), and so-called truly hybrid entangled

states (those which cannot be described in an overall finite-dimensional Hilbert space). Physically relevant examples for states of either regime are presented and entanglement witnessing as well as quantification are discussed. Regarding witnessing the well-known inseparability criteria by Shchukin and Vogel play a crucial role [1]. Quantification may be accomplished by describing the states in finite-dimensional subspaces and employing discrete-variable measures such as the logarithmic negativity. [1] E. Shchukin and W. Vogel, Phys. Rev. Lett. 95, 230502 (2005).

Q 7.8 Mon 12:15 SCH A118

Entanglement of four-qubit mixed states quantified with polynomial invariants — •Christopher Eltschka[1], Oliver Viehmann[2], and Jens Siewert[3,4] — [1]Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — [2]Physics Department, ASC, and CeNS, Ludwig-Maximilians-Universität, München, Germany — [3]Departamento de Química Física, Universidad del País Vasco - Euskal Herriko Unibertsitatea, Bilbao, Spain — [4]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

Recent work [1, 2] underlines the importance of polynomial SL invariants for classification and quantification of multipartite entanglement. For mixed states, the corresponding monotones are defined through convex-roof extension. In addition to the difficulties of calculating the convex roof, starting with four qubits there exists a continuum of monotones to choose from.

We study the mixed state entanglement of GHZ diagonal states of four qubits by calculating selected monotones. We discuss the implications for the classification of mixed state entanglement and compare with other criteria for entanglement in multipartite mixed states [3].

[1] Gour G., Phys. Rev. Lett. 105, 190504 (2010)
[2] Viehmann O., Eltschka C. and Siewert J., unpublished
[3] Gühne O. and Seevinck M., New J. Phys. 12, 053002 (2010)

Q 7.9 Mon 12:30 SCH A118

Entanglement verification with realistic measurement devices via squash models — •Tobias Moroder[1], Otfried Gühne[1,2], Normand Beaudry[3], Marco Piani[4], and Norbert Lütkenhaus[4] — [1]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria — [2]Department of Physics, University of Siegen, Germany — [3]Institute for Theoretical Physics, ETH Zurich, Switzerland — [4]Institute for Quantum Computing, Waterloo, Canada

Many protocols and experiments in quantum information science are described in terms of simple measurements on qubits. However, in a real implementation, the exact description is more difficult and more complicated observables are used. The question arises whether a claim of entanglement in the simplified description still holds, if the difference between the realistic and simplified model is taken into account.

We show that a positive entanglement statement remains valid if a certain linear map connecting the two measurement models exists. For entanglement verification this map only needs to be positive, but not necessarily completely positive as required in tasks like quantum key distribution, where this idea called squash model is already quite common. However this offers the possibility to employ this technique even for measurement setups which do not possess a completely positive squash model. The well-known polarization measurement using only threshold detectors, which is extensively used in optical experiments, represents a physical relevant example for which this new technique can indeed be applied.

Q 7.10 Mon 12:45 SCH A118

Shifting entanglement from states to observables — •Kedar Ranade[1] and Nathan Harshman[2,1] — [1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm — [2]Department of Physics, American University, Washington DC

We illustrate that for any pure state on a finite-dimensional Hilbert space we can construct observables that induce a tensor product structure such that the amount of entanglement of the state may take arbitrary values. In particular, we provide an example of how to construct observables on a d-dimensional system such that an arbitrary known pure state can be treated as maximally entangled. In effect, we show how entanglement properties can be shifted from states to observables.