QI 16: Concepts and Methods I

Time: Wednesday 11:00–13:00 Location: B302

QI 16.1 Wed 11:00 B302

Taming the Rotating Wave Approximation — •Daniel Burgarth[1,2], Paolo Facchi[3], Robin Hillier[4], and Marilena Ligabo[3] — [1]Macquarie University — [2]FAU Erlangen — [3]Bari University — [4]Lancaster University

The Rotating Wave Approximation (RWA) is one of the oldest and most successful approximations in quantum mechanics. It is often used for describing weak interactions between matter and electromagnetic radiation. In the semi-classical case, where the radiation is treated classically, it was introduced by Rabi in 1938. For the full quantum description of light-matter interactions it was introduced by Jaynes and Cummings in 1963. Despite its success, its presentation in the literature is often somewhat handwavy, which makes it hard to handle both for teaching purposes and for controlling the actual error that one gets by performing the RWA. Bounding the error is becoming increasingly important. Recent experimental advances in achieving strong light matter couplings and high photon numbers often reach regimes where the RWA is not great. At the same time, quantum technology creates growing demand for high-fidelity quantum devices, where even errors of a single percent might render a technology useless for error-corrected scalable quantum computation. I will report a conceptually simple way of explaining it and show how to tame it by providing non-perturbative error bounds, both for the semi-classical case and the full quantum case.

QI 16.2 Wed 11:15 B302

On the validity of the rotating wave approximation for interacting harmonic oscillators — •Paul Lageyre[1], Alessandro Ferreri[1], G. S. Paraoanu[2], Frank K. Wilhelm[1,3], Andreas W. Schell[4,5], and David Edward Bruschi[1,3] — [1]Forschungzentrum Jülich, 52425 Jülich, Germany — [2]Aalto University School of Science, FI-00076 AALTO, Finland — [3]Universität des Saarlandes, 66123 Saarbrücken, Germany — [4]Leibniz Universität Hannover, 30167 Hannover, Germany — [5]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

The rotating wave approximation (RWA) is widely used in the study of the dynamics of quantum systems. Within the interaction picture, terms in the Hamiltonian modelling two (or more) coupled quantum system acquire a phase factor. The RWA prescribes that terms rotating faster in phase with time tend to average out, and thus can be neglected in respect to slower rotating ones, which dominate the dynamics. The RWA is particularly easier to prove valid if the coupling is weak enough. Regardless of the success in applying this approximation, a deeper understanding of its domains of validity and the degree of error introduced otherwise would be greatly beneficial.

In this work we quantify the deviation from the full dynamics of coupled harmonic oscillators if the RWA is applied. We employ techniques from symplectic geometry and are able to directly relate the error introduced to the squeezing-like terms in the Hamiltonian that are dropped. We compute analytical expressions for the set of pure Gaussian states and discuss further applications.

QI 16.3 Wed 11:30 B302

Using beamsplitters as analogues for quantum mechanical joint spin measurements — •Hasan Ozgur Cildiroglu — Ankara University Dögol St. 06100 Ankara/Turkiye

Beamsplitters are optical and quantum mechanical components used to split incident light or particle beam at a designated ratio into two separate beams. The use of lossless beamsplitters with phase retarders reveals essential properties. In particular, they can be used as analogues to joint spin measurements in entangled quantum systems. In this study, after investigating this special property of beamsplitters, it will be tested in various hybrid gedanken experimental setups. Thus, a new method will be introduced for experimental testing of Bell-CHSH inequalities.

QI 16.4 Wed 11:45 B302

Quantum Correlations in Molecules: From quantum resourcing to chemical bonding — •Lexin Ding[1,2], Stefan Knecht[3,4], Zoltán Zimborás[3,5,6], and Christian Schilling[1,2] — [1]Ludwig Maximilian University of Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Germany — [3]Algorithmiq Ltd., Helsinki, Finland — [4]ETH Zurich, Switzerland — [5]Wigner Research Centre for Physics, Budapest, Hungary — [6]Eötvös Lorán University, Budapest, Hungary

The second quantum revolution is all about exploiting the quantum nature of atoms and molecules to execute quantum information processing tasks. To boost this growing endeavor and by anticipating the key role of quantum chemistry therein, our work establishes a framework for systematically exploring, quantifying and dissecting correlation effects in molecules. By utilizing the geometric picture of quantum states we compare – on a unified basis and in an operationally meaningful way – total, quantum and classical correlation and entanglement in molecular ground states. To unlock and maximize the quantum informational resourcefulness of molecules an orbital optimization scheme is developed, leading to a paradigm-shifting insight: A single covalent bond equates to the entanglement 2ln(2). This novel and more versatile perspective on electronic structure suggests a generalization of valence bond theory, overcoming deficiencies of modern chemical bonding theories.

QI 16.5 Wed 12:00 B302

Witnessing quantum non-Markovianity for high-entropy states using quasi-probability distributions — •Moritz Ferdinand Richter, Irene Ada Picatoste Fernández, and Heinz-Peter Breuer — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Memory effects in the dynamics of open quantum systems can be characterized by the flow of information between the open systems and its environment [1]. Quantum non-Markovian dynamics features a flow of information from the environment back to the open system. A commonly used measure quantifying this information backflow is based on the evaluation of the trace distance between two quantum states evolving in time according to a family of quantum dynamical maps. Yet, the computation of this measure becomes increasingly demanding in case of continuous variable systems with increasing entropy of the states at hand. We present a witness for quantum non-Markovianity which is based on the Kolmogorov distance between quasi-probability distributions [2]. Furthermore, we show that this witness is particularly efficient in high-entropy scenarios, and apply it to the determination of non-Markovianity in quantum Brownian motion [3].

[1] H.-P. Breuer, E.-M. Laine, J. Piilo and B. Vacchini, Rev. Mod. Phys. 88, 021002 (2016).

[2] M. F. Richter, R. Wiedenmann and H.-P. Breuer, arXiv:2210.06058 [quant-ph].

[3] S. Einsiedler, A. Ketterer and H.-P. Breuer, Phys. Rev. A 102, 022228 (2020).

QI 16.6 Wed 12:15 B302

Trajectory Representation of non-Markovian Quantum Dynamics — •Charlotte Bäcker, Konstantin Beyer, and Walter Strunz — Technische Universität Dresden, 01062 Dresden

The Markovian evolution of quantum systems can be described with the help of the well-known GKSL master equation. Quantum non-Markovianity is often associated with some backflow of information from the environment into the system. This backflow of information is closely related to the presence of memory effects and can result in negative decay rates in Lindblad-type master equations.

We address the question of whether such memory effects have to be quantum or if they can be modelled by classical memory only. We show how to obtain non-Markovian Lindblad-type master equations with time-dependent decay rates from trajectories described by consecutive classically conditioned measurements.

QI 16.7 Wed 12:30 B302

Optimizing the atom transport of neutral atoms between distant super-lattice sites — •Cristina Cicali[1,2], Robert Zeier[1], Felix Motzoi[1], and Tommaso Calarco[1,2] — [1]Forschungszentrum Jülich,Peter Grünberg Institute, Quantum Control (PGI-8), 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany

A variety of quantum platforms have demonstrated a capacity for efficiently manipulating quantum states to simulate macroscopic properties or to implement quantum gates. High-fidelity quantum oper-

ations rely on the precise control over the quantum system in order to minimize possible error sources such as decoherence. Within the BMBF project FermiQP, we are working together with the group of Christian Groß in Tübingen, on optimizing protocols to transport via optical tweezers the neutral atoms trapped in a two-dimensional super lattice. Optimized protocols aim at maximizing the transport velocity while considering error sources coming from excitation of the motional ground state of the atom, the non-deterministic imperfections in the optical apparatus, coming from aberrations and diffraction in the tweezers, as well as the presence of further atomic wells in the lattice. We present first numerically optimized example trajectories for the atom transport and discuss potential improvements to the protocols.

QI 16.8 Wed 12:45 B302

Optical cavities based on optical Tamm states for application in quantum optics — •Manuel Goncalves — Ulm University - Inst. of Experimental Physics, Ulm, Germany

Single optical Tamm states arise on junctions of one-dimensional binary photonic crystals of different Zak phase (a topological invariant). By stacking multiple crystals of alternating Zak phase multiple photonic modes arise in the band gap. Differently from Fabry-Perot cavities, structures based on multiple optical Tamm states exhibit more modes than the number of coupled cavities. An analysis of the optical properties of the modes is presented.

These cavities can achieve large quality factors, have small mode volume, due to the short cavity length (half-wavelength), and are tunable by varying the angle of incidence of external illumination. Due to these properties, they can be used in quantum optics applications and substitute the much larger Fabry-Perot cavities.