Book of Abstracts

Universidad del Valle
Faculty of Exact and Natural Sciences
Department of Physics
Cali-Colombia
September-2012

Presentation

Born from The First National Workshop on the Physics of Quantum Information and Computation (February 2010, Universidad Nacional-Bogotá), The International Workshop on Quantum Coherence and Decoherence-IWQCD1 seeks to strengthen ties within the national scientific community that is expert in these areas. The aim of the IWQCD1 is to bring back members of the most important groups in Colombian research in a suitable space to present new results, exchange ideas and to assess prospects for future collaborative work. In its new format, The IWQCD1 poses to extend the context of the discussion and invite a select group of international experts, some of which will be in charge of short courses of three hours each.

The First National Workshop on the Physics of Quantum Information and Computation (2010, Bogotá-Colombia)

1 IWQCD1 Schedule

Universidad del Valle

años 1945 - 2010

international workshop on quantum coherence & decoherence–IWQCD1

IWQCD1 Sept. 24-28 2012

schedule

Monday

- 8:00-8:15 — Opening
- 8:15-9:15 (Chair: Sánchez-Soto) — A. Buchleitner
- 9:15-10:15 — Z. Hradil
- 10:15-11:00 — Coffee-Registration
- 11:00-12:00 — E. Solano
- 12:00-12:30 — G. Arruda
- 12:30-15:00 — Lunch
- 15:00-15:45 (Chair: Fanchini) — A. Reyes
- 15:45-16:05 — A. Schlief
- 16:05-16:25 — E. González
- 16:25-16:55 — O. Rendón
- 16:55-17:25 — Coffee Break
- 17:25-18:10 (Chair: Pachón) — C. Viviescas
- 18:10-18:30 — S. Solorzano

Tuesday

- 8:00-9:00 (Chair: Viviescas) — A. Buchleitner
- 9:00-10:00 — Z. Hradil
- 10:00-10:30 — Coffee Break
- 10:30-11:30 — E. Solano
- 11:30-12:15 — T. Dittrich
- 12:15-15:00 — Lunch
- 15:00-15:45 (Chair: Hildner) — L. Quiroga
- 15:45-16:05 — O. Acevedo
- 16:05-16:25 — A. Gómez-Azuero
- 16:25-16:45 — C. Arango
- 16:45-17:15 — Coffee Break
- 17:15-17:45 (Chair: Dittrich) — F. Rodríguez
- 17:45-18:15 — L. Pachón

Wednesday

- 8:00-9:00 (Chair: Reyes) — A. Buchleitner
- 9:00-10:00 — Z. Hradil
- 10:00-10:30 — Coffee Break
- 10:30-11:30 — E. Solano
- 11:30-12:15 — B. Rodríguez
- 12:15-15:00 — Lunch
- 15:00-16:00 (Chair: Quiroga) — R. Hildner
- 16:00-16:45 — J.H. Reina
- 16:45-17:05 — C. Susa
- 17:05-17:35 — Coffee Break
- 17:35-17:55 (Chair: Rendón) — A. Ducuara
- 17:55-18:25 — F. Fanchini
- 18:25-20:00 — Poster Sesion

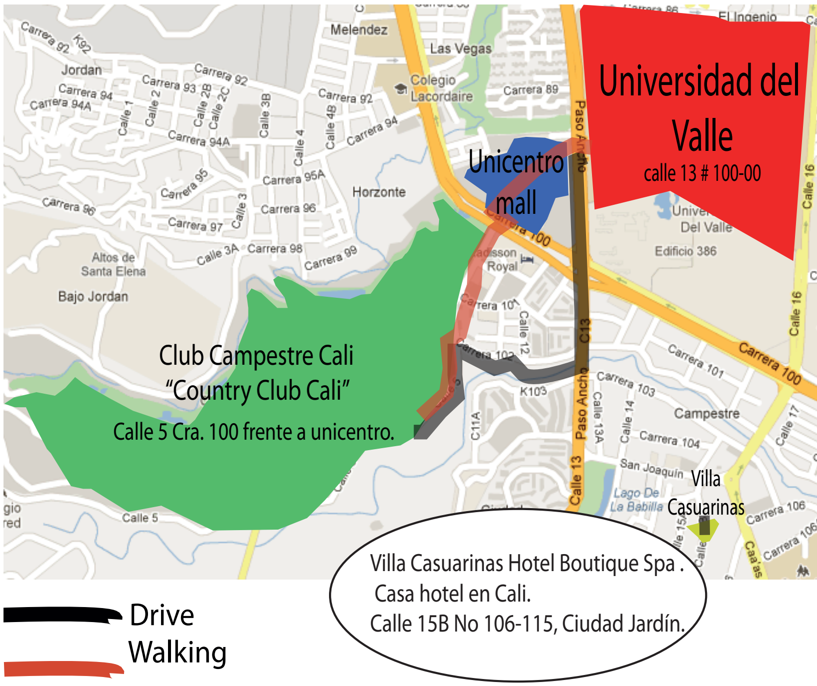
Thursday

- 8:00-12:00 — Excursion/Discussions
- 12:00-14:00 — Photo/Nirvana Lunch
- 14:00-15:00 (Chair: Valencia) — L. Sánchez-Soto
- 15:00-15:45 — L. Sánchez-Soto
- 15:45-16:15 — Coffee Break
- 16:15-17:00 (Chair: Ferney) — H. Vinck Posada
- 17:00-17:20 — G. Cipagauta
- 17:20-17:40 — D. Urrego
- 17:40-18:00 — F. Gómez
- 18:00 — Return

Friday

- 8:00-10:00 (Chair: Boris) — L. Sánchez-Soto
- 10:00-10:30 — A. Valencia
- 10:30-11:00 — Coffee Break
- 11:00-11:30 (Chair: Arruda) — J. Restrepo
- 11:30-11:50 — O. Calderon
- 11:50-12:10 — P. Díaz
- 12:10 — Closing Lunch

2 Useful Maps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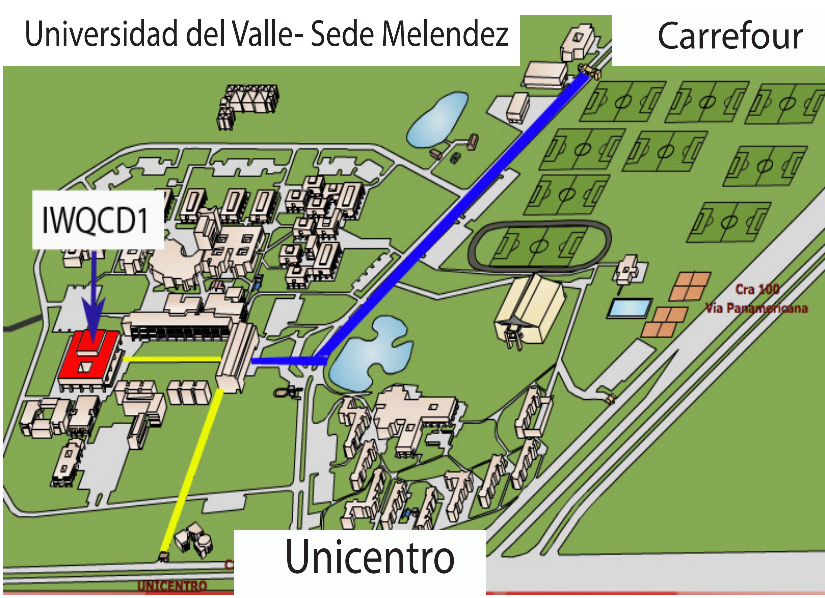
El Ingenio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Via Panamericana
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Contents

3 Short Courses:

3.1 Correlations and entanglement of identical particles

Andreas Buchleitner
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Abstract

Entanglement theory is well developed, at least in what concerns its fundamental ramifications, for distinguishable particles. This is less so when it comes to identify the non-classical correlations inscribed into collections of identical particles, in particular when these undergo dynamics which render them distinguishable, in the course of time. The lectures will address the competition of quantum statistical and dynamical features as witnessed by correlation functions and entanglement measures for identical particles.

3.2 Quantum tomography and information

Z. Hradil
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Abstract

Quantum information technologies have recorded enormous progress within the recent fifteen years. They have developed from the early stage of thought experiments into nowadays almost ready-to-use technology. The quantum

state is not an observable and as such it cannot be measured in the traditional sense of this word. Information encoded in a quantum state may be portrayed by various ways yielding the most complete and detailed picture of the quantum object available. Due to the formal similarities between the quantum estimation and medical non-invasive 3D imaging, this method is also called quantum tomography. Many different physical implementations of quantum tomography have been devised recently unravelling even the most exquisite and fragile non-classical effects. Progress has been made on the detection as well as in mathematical processing. The original linear methods based on the inverse Radon transformation are prone to producing artifacts. For such reasons, the simple linear methods are gradually being replaced by statistically motivated methods, for example maximum-likelihood (ML) tomography [1, 2] . The quantification of all relevant errors is an indispensable but often neglected part of any tomographic scheme used for quantum diagnostic purposes. We show how to use prior information and point out the connection between maximum likelihood estimation and concepts of information and entropy. We derive a reconstruction scheme, where both the likelihood and von Neumann entropy functionals are maximized in order to select the most-likely estimator with the highest entropy, that is the least-biased one. In this scheme partial knowledge and ignorance about the true state can be combined in an exquisit and robust reconstruction protocol [3]. The theory will be illustrated on several pedagogical examples as well as applications used in diagnostics of non-classical behavior.

This work has been done in collaboration with J. Řeháček.

Keywords: quantum information, quantum tomography, diagnostics of non-classical behavior

[1] Z. Hradil, Phys. Rev. A **55**, R1561 (1997).

[2] Z. Hradil, J. Řeháček, J. Fiurasek, and M. Jezek, Maximum Likelihood Methods in Quantum Mechanics, in *Quantum State Estimation*, Lecture Notes in Physics (ed. M.G.A. Paris, J. Rehacek), 59-112, Springer, 2004.

[3] Y.S. Teo, H. Zhu, B.-G. Englert, J. Řeháček, and Z. Hradil, Quantum-State Reconstruction by Maximizing Likelihood and Entropy, Phys. Rev. Lett. **107**, 020404 (2011).

3.3 Quantum simulations and quantum information

Enrique Solano

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Abstract

In this Short Course I will be addressing the following topics:

1. Quantum simulations and implementations

   (a) Quantum optics: trapped ions, optical lattices, quantum photonics
   (b) Circuit QED and superconducting qubits

2. Quantum simulations in trapped ions

   (a) Analog and digital quantum simulations
   (b) Dirac equation: Zitterbewegung and Klein paradox
   (c) Interacting fermions and quantum field theories

3. Quantum simulations in circuit QED

   (a) Quantum optics and circuit QED
   (b) Quantum Rabi model
   (c) Relativistic quantum mechanics

3.4 Quantum optics in phase space: a practitioner perspective

Luis L. Sánchez-Soto [1,2]

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[2]Max-Planck-Institut für die Physik des Lichts, 91058 Erlangen, Germany

Abstract

Phase-space methods were introduced in the very early times of quantum mechanics to avoid some of the troubles arising in the abstract Hilbert-space formulation. In this way, one can formally represent quantum phenomena as a statistical theory on a properly chosen classical phase space. In this short course I will show how the use of these

techniques allows one to deal in a unified way with continuous and discrete degrees of freedom, analyzing also the peculiarities of periodic variables. As two guiding examples, we will treat the orbital angular momentum of photons and present the basic tools of qubism; that is, the art of properly picturing qubits.

Keywords: quantum information
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4 Keynote Talk:

4.1 Quantum coherence in organic systems: From small molecules to photosynthetic antenna complexes

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Abstract

Quantum mechanical effects in biological systems are intriguing and lively debated issues. In particularly fascinating recent observations surprisingly long-lived quantum coherences in the initial ultrafast energy-transfer steps in photosynthesis have been identified that are driven by a careful balance between coherence, dissipation and decoherence. However, it is still unclear, how nature designed light-harvesting complexes that are robust against external perturbations and thermal disorder, and whether quantum coherent transfer can assist to optimise the flow of energy despite disorder. Owing to the large structural and electronic heterogeneity of bio-systems, such questions cannot be addressed by conventional ultrafast spectroscopic techniques, which intrinsically average over large ensembles.

To study ultrafast coherences in large and complex organic molecules at the level of *individual* quantum systems under ambient conditions, we have recently combined femtosecond pulse-shaping techniques with single-molecule detection schemes. In a proof-of-principle experiment on a model system, individual terrylene molecules embedded in a polymer matrix, we have shown to be able to resolve ultrafast electronic coherences and the femtosecond coherence decay by employing a phase-controlled double-pulse

excitation method. We also observed and manipulated vibrational wave-packets in single chromophores by adapting the time and phase distributions of the laser field to the ultrafast molecular dynamics. We have very recently extended these techniques to resolve quantum coherent energy transfer within single photosynthetic light-harvesting complexes. Quantum coherences between electronically coupled energy eigenstates have been found to persist at least 400 fs at room temperature, substantially longer than previously reported. We also have identified distinct energy transfer pathways in each individual complex. Remarkably, these transfer pathways within single complexes change on time scales of seconds induced by thermally activated rearrangements of their protein scaffolds. These data imply that quantum effects play a biological role as they render energy transfer in photosynthesis robust in the presence of disorder.

Talk based on joint work with D. Brinks and N. F. van Hulst (ICFO, Barcelona), and R. J. Cogdell (University of Glasgow).

Keywords: photosynthesis, organic molecules, coherence, dephasing

5 Plenary Talks:

5.1 The vacuum at the foundations of quantum optics

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[2]Max-Planck-Institut für die Physik des Lichts, 91058 Erlangen, Germany

Abstract

In the classical theory of electromagnetism, the permittivity ε_0 and the permeability μ_0 of free space are constants whose magnitudes do not seem to possess any deeper physical meaning. By replacing the free space of classical physics with the quantum notion of the vacuum, we speculate that the values of the aforementioned constants could arise from the polarization and magnetization of virtual pairs in vacuum. A classical dispersion model with parameters determined by quantum and particle physics is employed to estimate their values. We find the correct orders of magnitude. Additionally, our simple assumptions yield an independent estimate for the number of charged elementary particles based on the known values of ε_0 and μ_0 and for the volume of a virtual pair. Such interpretation would provide an intriguing connection between the celebrated theory of classical electromagnetism and the quantum theory in the weak field limit.

5.2 Entanglement, particle identity and the GNS construction

Andrés F. Reyes-Lega
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Abstract

In this talk I will present an approach to entanglement which is based on the Gelfand-Naimark-Segal (GNS) construction. The conventional approach to the emergence of mixed from pure states based on taking partial traces is replaced by the more general notion of the restriction of a state to a subalgebra. For bipartite systems of nonidentical particles, this approach reproduces the standard results. But it also very naturally overcomes the limitations of the usual treatment of systems of identical particles.

The content of this talk is based on joint work with A.P. Balachandran, T.R. Govindarajan and A.R de Queiroz.

Keywords: quantum information, entanglement, operator algebras
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5.3 Quantum trajectory description of entanglement dynamics

Ivonne Guevara[1] and Carlos Viviescas[1]
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Abstract

We present and overview of the characterization of the dynamical evolution of entanglement in open two-qubit system by means of diffusive quantum trajectories. We show how this method allows for a complete description of this phenomenon providing deterministic evolution equations for some experimentally relevant cases, and excellent upper bounds for the entanglement dynamics in some other cases. For all cases considered we propose quantum optical experimental setups which allow for a real time measurement of the entanglement time evolution.

Keywords: quantum information, computation, decoherence, and entanglement
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5.4 Classical information exchange and quantum entanglement between two coupled harmonic oscillators

Thomas Dittrich
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Abstract

I present a detailed study of the information exchange between two coupled harmonic oscillators. Based on comprehensive analytical solutions for the time evolution of all pertinent quantities, specifically the classical and quantum phase-space densities and information contents (in terms of Shannon information and von Neumann entropy, resp.)

for the total system as well as for the two subsystems, and on the conservation of the total information on both levels, I compare the classical to the quantum information flow and identify relations between them. As initial preparations, I shall contrast two complementary extremes with one another, a classically large incoherent Gaussian superposition of coherent states as closest quantum mechanical approximation to the corresponding classical initial distribution, and a highly excited pure state of the pair of coupled oscillators. Among the insights gained I shall point out in particular how periodic "sudden deaths of entanglement" on the quantum side coincide with sign reversals of the correlation between the two subsystems on the classical side, both repeating periodically with the frequency of beats between the coupled oscillators. Illustrating the relation of classical and quantum information on a common footing, information flow in phase space, the results provide a prototypical example of pedagogical value and suggest to be extended towards higher numbers of coupled oscillators, in order to analyze in depth the relationships between entanglement, information flow, and decoherence.

Keywords:
Shannon information; von-Neumann entropy; coupled harmonic oscillators; Wigner function; information flow; sudden death of entanglement; conditional information; correlation.
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5.5 Nonequilibrium thermal spatial and temporal quantum correlations

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Abstract

One of the most important challenges to detect superposition of quantum macroscopic states is the fragility of these states to decoherence effects. For quantum systems in contact with heat reservoirs at an unique and fixed temperature the equilibrium thermal entanglement has been extensively studied. However, the entanglement of nonequilibrium quantum systems has been scarcely considered. New possibilities for entanglement production and manipulation in nonequilibrium situations, where quantum coherences are dominant, are emerging. In this talk we discuss different aspects of the relationship between thermodynamical nonequilibrium steady-state features with quantum correlation properties of nanosystems coupled to two heat baths at different temperatures (T_1 and T_2).

First, we consider spatial quantum correlations as measured by the entanglement of formation. We show an intimate relationship between stationary heat current, entropy production rate and concurrence for a simple two-qubit system. We show that while the quantum informational entropy remains constant in a steady-state situation, the rate of production of thermodynamic entropy is linearly proportional to the nonequilibrium concurrence. We find an enhanced-suppressed entanglement transition which takes place when a temperature gradient is applied. Additionally, a temperature gradient allows for producing quantum states with exactly the same amount of entanglement as for an equilibrium situation but with different entropies and heat currents. Second, we discuss two-time quantum correlations under nonequilibrium thermal conditions as given by the so-called Leggett-Garg inequalities (LGIs). For a macroscopic object, in a superposition of different states, LGIs predict restrictions of classical features through macroscopic quantum coherence. We show that for a bipartite quantum system LGIs violations, as well as quantum two-time correlations, are more robust than in an equilibrium case, as a function of the average temperature $T_M = (T_1 + T_2)/2$, for a finite range of temperature gradients, $\Delta T = T_2 - T_1$. By using a Kraus operators formalism, in the stationary limit, we demonstrate numerically and analytically that quantum correlations and maximal LGIs violations show different power law behaviors in a plane T_M vs. Γ, where Γ denotes the Markovian coupling with the thermal reservoirs. For the special case of a quantum system formed by two interacting qubits we compare the range of parameters where LGIs violations are detected with a spatial quantum correlation measure such as concurrence.

Keywords: quantum information, two-photon absorption, decoherence, entanglement, quantum correlations
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5.6 Exciton entangled-two-photon absorption by semiconductor quantum wells

F.J. Rodríguez, L. J. Salazar, D. Guzmán and L. Quiroga

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Abstract

Quantum correlations are among the most surprising consequences of quantum mechanics. One of the most important experimental challenges is to detect such correlations in condensed matter systems where decoherence effects are stronger than in atomic systems. At present, several studies have been done to produce and characterize entangled photons. One successful technique for generating quantum-correlated or entangled photon pairs is known as spontaneous parametric down-conversion (SPDC). However, scarce research has been done on the effects that these entangled photons produce on semiconductor quantum systems. Of special interest is the understanding of the relationship between photon-correlation features and absorption spectra. We show theoretical results on the dependence of the excitonic entangled-two-photon absorption by a semiconductor quantum well on a variable such as the entanglement time of the photon pair. We report on the connection between biphoton entanglement, as quantified by the Schmidt number, and absorption by a semiconductor quantum well. In particular, the entangled-photon absorption displays very unusual features depending on space-time-polarization biphoton parameters and absorber density of states for both bound exciton states as well as for unbound electron-hole pairs. We found that exciton oscillator strengths are highly increased when photons arrive almost simultaneously in an entangled state. Finally, we perform a comparative study of the absorption response of a semiconductor quantum well for differently quantum-correlated signal/idler photon pairs such as frequency-anti-correlated, unentangled and frequency-correlated biphoton states. Two-photon-absorption becomes a highly sensitive probe of photon quantum correlations when narrow semiconductor quantum wells are used as two-photon absorbers.

Keywords: quantum information, two-photon absorption, decoherence, entanglement, quantum correlations
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5.7 Microcavity quantum electrodynamics: From atoms to quantum dots

B.A. Rodríguez R.
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Abstract

Microcavity quantum electrodynamics (μC–QED), the interplay between quantum optics and solid state systems, has recently emerged as one of the most active and promising research fields. A single quantum emitter, a qdot (QD) or a qwell, coupled to one confined light mode in a photonic crystal or a micropillar-cavity is one of these μC–QED

systems with more perspectives for device applications such as single photon sources and quantum information processing. Furthermore, this system exhibits fundamental physical phenomena such as Purcell effect, non-classical light, strong coupling, and polariton laser (non-equilibrium BEC). In this talk a few recent relevant experimental and theoretical results obtained on these systems are briefly discussed. Using a simple fully quantum model in an effective two-level exciton scheme that takes into account the system–environment interaction, we study the polariton–laser and photon–laser regimes arising in a μC-QD. The non-hamiltonian processes induced by the environment are taken into account via a Born-Markov master equation. Our numerical calculations of the emission linewidth, emission energy, integrated intensity and second- and third-order correlation functions are in good qualitative agreement with reported experimental results. We show that the transition from the polariton– to the photon–laser regime can be defined through the critical points of both the negativity and the linear entropy of the steady state. Furthemore, we investigate the effect of a polariton bath in the photoluminescence spectrum. By fitting an experimental spectrum to extract the values of all parameters appearing in the master equation, we show that the polariton pumping and loss rates are comparable to the other parameters and therefore we have a first evidence that the polariton bath we proposed has a significant role in the dynamics of a μC-QD system.

Keywords: quantum electrodynamics, microcavity, Purcell effect, quantum correlations

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5.8 Quantum coherence, entanglement and correlations in coupled quantum emitters

John H. Reina
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Abstract

In this talk we will address fundamental quantum mechanical effects such as entanglement, correlations, and decoherence that arise in two nano-optics setups of different physical origin. In the first part, we solve the problem of quantifying and optically controlling the dissipative dynamics of entanglement, classical and quantum correlations in a setup of externally driven individual quantum emitters (e.g., dipole-coupled single molecules). Such coupled single molecules have the potential for scalable quantum computing due to their amenability to plasmonic nano-circuitry integration.

In the second part, we compute the dissipative quantum coherent dynamics followed by a biomolecular network (the FMO complex), arguably the less complex unit of a photosinthetic nano bio-device designed by Nature. We demonstrate that quantum coherence generated in such systems is favoured and can be maintained for times up to $\sim$ 1ps due to the constructive role played by the non-Markovian biomolecular environment, i.e., the protein solvent surrounding bath helps to preserve the coherence during the evolution of the biomolecular excitons. Here the simulations are somewhat more involved and are carried out by means of the numerically exact method of quasi-adiabatic propagation via Feynman integration. The results reveal the role of quantum coherence in order to maximize the energy transport efficiency and minimize the average time for the excitation transfer.

Keywords: Quantum and classical correlations, entanglement, driven systems, light harvesting complexes, nano-optics, Markovian and non-Markovian decoherence.

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5.9 Quantum evolution of a light star state in a microcavity-quantum dot system

Juan Camilo López-Carreño[1], **Juan Pablo Restrepo-Cuartas**[2], **Herbert Vinck**[1]

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[2]Instituto de Física, Universidad de Antioquia, AA1226 Medellín, Colombia.

Abstract

In this paper, we study the dissipative dynamics for a quantum dot microcavity system using the master equation in the Born-Markov formalism. In particular, we focus on the case of an initial condition corresponding to a star state, this due to the fact that only recently, through the use of nonlinear media, this quantum state of light can be engineered for this kind of system. In terms of results, we compare both dynamics Hamiltonian and dissipative through quantities as negativity, linear entropy and fidelity. Moreover, we find the Wigner function for the density matrix of the reduced quantum state, and observe its evolution confirming the statistical composition of the quantum state of light.

Keywords: Quantum information, quantum computation, Star state.

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6 Contributed Talks:

6.1 Exact dynamics of single qubit gate fidelities under the measurement-based quantum computation scheme

L. G. E. Arruda[1], **F. F. Fanchini**[2], **R. d. J. Napolitano**[1], **J. E. M. Hornos**[1] **and A. O. Caldeira**[3]
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[3]Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, P.O. Box 6165, CEP 13083-970, Campinas, SP, Brazil

Abstract

Measurement-based quantum computation is an efficient model to perform universal computation. Nevertheless, theoretical questions have been raised, mainly with respect to realistic noise conditions. In order to shed some light on this issue, we evaluate the exact dynamics of some single qubit gate fidelities using the measurement-based quantum computation scheme when the qubits which are used as resource interact with a common dephasing environment. We report a necessary condition for the fidelity dynamics of a general pure N-qubit state, interacting with this type of error channel, to present an oscillatory behavior and we show that for the initial canonical cluster state the fidelity oscillates as a function of time. This state fidelity oscillatory behavior brings significant variations to the values of the computational results of a generic gate acting on that state depending on the instants we choose to apply our set of projective measurements. As we shall see, considering some specific gates that are frequently found in the literature, neither fast application of the set of projective measurements necessarily implies high gate fidelity, nor slow application thereof necessarily implies low gate fidelity. Our condition for the occurrence of the fidelity oscillatory behavior shows that the oscillation presented by the cluster state is due exclusively to its initial geometry. Other states that can be used as resources for measurement-based quantum computation can present the same initial geometrical condition. Therefore, it is very important for the present scheme to know when the fidelity of a particular resource state will oscillate in time and, if this is the case, what are the best times to perform the measurements.

Keywords: open quantum systems, one-way quantum computation, decoherence and cluster states

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6.2 Entanglement of identical particles

Otto Rendón[1]

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Abstract

We have studied, how measuring device modifies the degree of entanglement in a system with two identical particles, and their statistics is controlled by the δ parameter, bosons $\delta = 1$ and fermions $\delta = -1$. The concurrence $C(|\Psi\rangle)$ characterizes the degree of entanglement in the system of two particles. When the states of one-particle are orthonormal, the concurrence is invariant under symmetrization or antisymmetrization.

Keywords: quantum information, identical particles, detection process, and entanglement

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6.3 Decoherence in *cis-trans* isomerization

Carlos A. Arango[1] **and Paul Brumer**[2]

[1]Departamento de Ciencias Químicas, Universidad Icesi, Cali, Colombia

[2]Chemistry Department, University of Toronto, Toronto, Ontario M5S 3H6 Canada

Abstract

Using Stock and Hahn models we study the decoherence in the cis-trans isomerization of retinal. For these models we calculate and compare classical and quantum decoherences from the square of the trace of the density matrix in energy and coordinate representation. For the extended model (25 dof) we use the time-dependent self-consistent field approximation to calculate the decoherence. The classical decoherence is obtained from Miller's mapping approach. The comparison of the classical and quantum and TDSCF decoherences shows a good agreement for the extended model of retinal but not for the reduced model (only 2 modes).

Keywords: quantum decoherence, cis-trans isomerization

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6.4 Environment-assisted one-photon coherent phase control

Leonardo A. Pachon and Paul Brumer
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Abstract

A well established result, in the coherent-control-of-states community, is that control over relative product cross sections using one-photon excitation is not possible in the weak field regime. This result was stated under the assumption of unitary time evolution. Here we show that when the environment and its initial correlations with the system are taken into account, then one-photon phase control is possible. We also discuss how this environment-assisted process can be enhanced in the low temperature regime and under the presence of non-Markovian dynamics.

Keywords:
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6.5 Shielding quantum discord through continuous dynamical decoupling

Felipe F. Fanchini
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Abstract

We investigate the use of dynamical decoupling to shield quantum discord from errors introduced by the environment. Specifically, a two-qubits system interacting with independent baths of bosons are considered. The initial conditions of the system were chosen as pure and mixed states, while the dynamical decoupling is achieved by means of continuous fields. The effects of the temperature on the shielding of dynamical discord is also studied. It is found that, depending on the initial state of the system, protecting dynamical discord via dynamical decoupling technique may not be advantageous compared to the free-evolution of the system below a certain time, which depends on the frequency of the protective field. Above this time, the shielding through dynamical decoupling becomes effective in comparison to the system free evolution. It is also shown that the time for which the shielding of the quantum discord becomes effective decreases as the temperature increases.

Keywords: quantum computation, decoherence, dynamical decoupling, quantum discord

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6.6 Engineering the joint spectrum of entangled photon pairs

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Abstract

Spontanesous parametric downconversion (SPDC) is an optical process, where a nonlinear crystal is pumped by an intense beam mediating the generation of two photons that satisfy energy and momentum conservation. The two-photon probability amplitude or biphoton that describes the quantum state of this light can show entanglement in frequency, momentum, and polarization degrees of freedom. This makes SPDC a ubiquitous source of photon pairs in quantum information processing tasks. Additionally, the simultaneous creation of the pair makes this light useful for several applications for example coherent anti-Stokes Raman scattering or as a tool for the generation of heralded single photons.

For various application, in addition to the simultaneous creation of the pair it is necessary to have a specific type of frequency correlation or a specific bandwidth. For example, correlated and anticorrelated photons can be used for enhanced protocols for distant clock synchronization and positioning while uncorrealted photons can be used to generate heralded single photons with high purity.

The joint spectrum of the photons generated by SPDC contains information about bandwidth, types of frequency correlation and the wave-form of the two-photon state. In this talk, we report techniques to control the shape of this joint spectrum by tuning parameters that are readily available in an experimental setup. In particular, it is reported the generation of correlated, anticorrelated and uncorrelated frequency photons. Additionally, the potentiality of the reported techniques to generate narrow temporal biphotons is discussed. This capability is desired in applications that require precise timing measurements.

Keywords: quantum information, computation, decoherence, and entanglement

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6.7 Decoherence induced by an ordered environment

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Abstract

In this seminar, I will address a few fundamental questions related to the decoherence and relaxation of quantum systems. In particular I will present the study of the full evolution of a two level system or qubit coupled to a bath composed of non-interacting and interacting electrons and I will focus on the case where the bath exhibits long range order. To study the effect on the time evolution of a qubit, of an environment which undergoes a transition to an ordered phase, we consider a qubit weakly coupled to a standard BCS superconductor. We find that ordering in the superconducting bath generically leads to an unfavorable faster-than-exponential decay of the qubit coherence. On the other hand, a coupling to the non-ordered sector of the bath can result in a drastic reduction of the qubit decoherence. Since these behaviors are endemic to the ordered phase, qubits can serve as useful probes of phase transitions in their environment.

Keywords: quantum information, decoherence, quantum statistical methods, broken symmetry phases

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7 Students Contributed Talks:

7.1 Quantum ontological models and the PBR theorem

Andrés F. Ducuara, Cristian E. Susa, and John H. Reina

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Abstract

Quantum mechanics is a proven successful theory; however, it is also a fact that there are conceptual ambiguities about its interpretation of *reality*, and arguments such as the EPR 'paradox' and Bell's inequalities point out such issues. Quantum ontological models (OM) were developed to tackle these ambiguities within a general, unified theoretical framework [1]. Features like completeness and locality in quantum mechanics were introduced formally in this context, and so, EPR and Bell arguments were reconstructed as well. A recent result, the Pusey-Barrett-Rudolph (PBR) theorem [2], states that if a physical system satisfies i) compatibility [3] and ii) non Post-Peierls ($\neg PP$) compatibility [4], it can be modeled by a ψ-ontic OM [2, 3], i.e., an OM which contains certain realism in the sense of Einstein's completeness. In this work, we use the restricted property of factorisability instead of compatibility and introduce a numerical approach to the PBR theorem: we test two sets of different initial states for an n-qubit register, and analyse the validity of the theorem when the system interacts with an environment, here represented by the action of simple quantum noisy channels which 'monitor' the system dynamics.

Keywords: Quantum information, ontological models, hidden variables, noisy channels.

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7.2 Plasmon-assisted quantum switching of correlations in distant emitters

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Abstract

An interesting property of metals, beyond that of reflecting light, is that under specific conditions, the light can propagate closely to the metal's surface without going away from it. This type of lightwave–the surface plasmons (SPs)– involves the free electrons of the metal's surface and thanks to their subwavelength character and confinement, the SPs have been been identified as prominent candidates to act as a mediator for coupling quantum emitters and light. We quantify the correlations in a two-emitter system in interaction with a one-dimensional dissipative plasmonic waveguide, and externally driven by a coherent laser field. We compute quantum, classical and total correlations,

and show that the emitters become, rather than entangled, strongly quantum correlated (in the sense of the quantum discord) via the plasmon bus. We provide a qubit decoupling mechanism whereby the emitters evolve completely independently from each other, even in the presence of the plasmon-mediated dipolar interaction. Coherent laser excitation may be used to enhance the dimer's steady-state discord and to switch on and off the correlations amongst distant qubits, a mechanism facilitated by the plasmon bus that can be exploited for quantum logic gating.
Work in collaboration with Richard Hildner (Universität Bayreuth and ICFO–Barcelona).

Keywords: Quantum and classical correlations, entanglement, plasmonics, driven systems, quantum decoherence, nano-optics.

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7.3 Parametrical quantum processing across a quantum phase transition

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Abstract

Quantum Phase Transitions (QPTs) are excellent examples of how many-body quantum systems can exhibit highly non-trivial behaviors associated to significant correlations among their components.

In such contexts, quantum information concepts and techniques are involved in the characterization and monitoring of both dynamical and equilibrium properties of the phases and boundaries. Also, the dynamical crossing of a QPT is especially important in the field of adiabatic quantum computation [1] where some quantum operations can be discarded as impractical, if the complications of crossing a quantum critical point exceed the computational gain of processing a big amount of qubits at the same time. In this work, by means of an efficient computational simulation, we explore the time evolution of finite-size Dicke models when the qubit-field interaction parameter is varied between low and high values, then crossing a critical threshold in its parameter space [2]. The efficiency of the parametrical driving has been measured by different kinds of quantum fidelities as well as with the excess energy, while different subsystem measures of entanglement and other quantum properties have been assessed in order to have a better picture and understanding of the underlying physics. We have found that results strongly depend on the rate of change of the interaction parameter as well as other properties of the path taken in parameter space (great memory effects). We have also found some regularities scaled according to the size of the system. The diabatic regime is characterized by size-proportional universal behaviors explained by the sudden quench approximation. As the near-adiabatic regime is approached, much more complex effects arise, and the scaling is more subtle.

Keywords: adiabatic quantum computation, fidelity, entanglement

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7.4 Can the exciton–polariton regime be defined by its quantum properties?

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Abstract

The solid–state realization of Bose–Einstein Condensation (BEC) has been achieved in exciton–polariton systems. These quasi–bosons, arising from the strong coupling between photons and electron–hole pairs in semiconductor microcavities (μ-C), have a high critical temperature due to their small effective mass (eight orders of magnitude smaller than hydrogen atom mass). After more than two decades of theoretical and experimental investigations, nowadays it is understood that the large occupation of the polariton ground state cannot be identified with usual thermodynamic equilibrium BEC states. Instead, the corresponding experimentally observed regime has been called polariton laser because of its dynamical nature and the gain in the light–emission intensity. The transition from this regime to a second one, identified with the well-known photon laser, has also been observed. In a recent work [Suárez-Forero *et al.*, arXiv:2012.2719v1], we use a simple fully quantum model in an effective exciton scheme that takes into account the system–environment interaction, in order to study the different regimes arising in a microcavity–quantum dot system. Our numerical calculations of the emission linewidth, emission energy, integrated intensity and second- and third-order correlation functions are in good qualitative agreement with reported experimental results. We show that the transition from the polariton-laser to the photon-laser regime can be defined through the critical points of both the negativity and the linear entropy of the steady state.

Keywords: entanglement, decoherence.
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7.5 Production of quantum random numbers

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Abstract

Using a qubit system, we are able to get random number sequences. Tests for statistical randomness are applied to each generated sequence. A truly random sequence comes from quantum events, while any other sequences don't show a real random behavior. The sequence from a classical event (or a computational program) can determine the next bit if a part of the sequence is known, because all classical events can described given that all parameters are known; these sequences are called pseudorandom sequences. On the other hand, a sequence coming from an event described by quantum mechanics hasn't a deterministic behavior, the output of the experiment can't be fixed, so even if one bit of the sequence is known, it is not possible to know the next bit.

In our experiment we use a standard assembly (similar to [1]) using three different sources of photons in order to get 3 different sequences with different parameters. We used an inexpensive laser of 650nm (as a standard assembly) for the first sequence; the second sequence comes from the same laser but using a rotating acrylic plate as a dispersion source and the third sequence comes from a red LED. In the experiment the photons are guided by two mirrors until they arrived to a beam splitting stage. Here photons arrive to a Polarizing Beam Splitter (PBS) after passing

through an adjustable waveplate, in order to obtain a 50% transmission (reflection); the input photon has two output paths. The source photon has a predefined polarization, which is the key to the PBS working as a controllable 50-50 beamsplitter. Then, the user must decide if a detection of a vertical (reflected) photon will be a logical one and a horizontal (transmitted) photon will be a logical zero or vice versa. Obtained sequences in our setup are about 300000 bits long for each case, and takes about 5 hours to obtain them.

There are a few algorithms to test if a sequence is random or not [2]. Most of them give a p value as a result, that says the sequence would be considered as random (non random) if $p > 0.01$ ($p < 0.01$) with a confidence of 99%. A potential improvement to the experiment is to get longer sequences, which potentially can get a better p value.

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Keywords: Quantum information and processing, Photon counting, Randomness, PBS

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7.6 Entanglement in hybrid solid-state quantum systems

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Abstract

Quantum entangled states are of great interest in modern physics both from a fundamental standpoint and for potential applications. In particular, the possibility of manipulating entangled states in macroscopic systems at high temperature is the basis for prospects of quantum technologies. Strong candidates for such quantum protocols are the nitrogen-vacancy (NV) defect centers in diamond for which an increasing body of experiments has demonstrated individual full optical writing/reading control of quantum information in the defect's electronic spin, even at room temperature. Moreover, dark nuclear spins directly coupled by hyperfine or dipolar interactions with the central NV spin can be controlled by applying suitable microwave and radiofrequency pulses. In this work we analyze the entanglement creation process in some solid-state NV based quantum systems. First, we consider two dipole coupled NV centers and calculate the entanglement between their electronic spins. By applying an external magnetic field we calculate quantum correlations as measured by the concurrence and quantum discord for different magnetic field strengths/orientations for both secular and non-secular dipole interactions. Furthermore, in order to get closer to actual experimental conditions we include the effects of a ^{13}C nuclear spin bath on the quantum correlation degradation. As a second system, we analyze the entanglement between nuclear spins themselves associated to

two NV centers (spin-1 ^{14}N nuclei) as nuclear spins are excellent qubits because they are well isolated from the environment (long T_2^* dephasing times). Although the nuclear spin interaction is weak as compared with the electronic spin interactions, we show how to entangle the nuclear spins by using the electronic spin as a mediator. We find optimal conditions to increase the interaction and therefore the entanglement. More recently, great interest has aroused in combining NV qubits with other quantum devices like superconductor qubits, semiconductor quantum dots and plasmon nanowires, yielding to new hybrid solid-state systems. The goal of these new hybrid quantum objects is to combine the advantages and strengths of each individual system to better explore novel phenomena that could eventually span robust quantum platforms. Consequently, we address the question about the feasibility of creating entanglement between two remotely separated NV by means of some other solid-state mediators such as two interconnected superconducting flux qubits or nanowire plasmons.

Keywords: Hybrid quantum systems, entangled states, NV centers in diamond, quantum correlations
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7.7 Quantum control of photons by a Landau-Zener-type process

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Abstract

We study the population temporal evolution in a two-level system (TLS) coupled to a cavity. For different initial prepared states like Fock or coherent Schrödinger cat states, the presence of collapses and revivals of the photon field can be controlled through a Landau-Zener-type process. Is studied both theoretically and numerically the collapse and revival, when the coupling between the TLS and the radiation field is in the regime of weak and strong coupling. In particular, in the steady state, we obtain analytical expressions for the population of the photon field in good agreement with numerical results when the initial state of the field is coherent.

Keywords: Landau-Zener type process, quantum control. E-mail: `fj.gomez34@uniandes.edu.co`

7.8 Estimating the spectrum of a density operator in an infinite dimensional Hilbert space

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Abstract

A very important problem in quantum information theory is estimating the spectrum of a density matrix. M. Keyl and R.F. Werner proposed a measurement that approximates the spectrum of a density operator in a finite dimensional Hilbert space. They proposed to measure a partition $\lambda \vdash n$, from a system of n copies of a state $\rho \in GL(d, \mathbb{C})$, such that each λ will have a probability of outcome $p_\lambda = f^\lambda s_\lambda(r)$. Here, f^λ denotes the dimension of the irreducible representation associated to λ in S_n, and $s_\lambda(r)$ is the Schur polynomial evaluated in the spectrum of ρ. In the case of finite d, those probabilities behave like $p_i \sim \exp(-nS(\overline{\lambda}||r^\downarrow))$, where S is the relative entropy between normalized λ and the spectrum ordered decreasingly. This follows from the polynomial growth of $s_\lambda(r)$ and the approximation $f^\lambda \approx \exp\left(-nH(\overline{\lambda})\right)$.

In the case of a partition with more parts, Vershik and Kerov proved that $f^\lambda \sim \exp\left(-\frac{c_1}{2}\sqrt{n}\right)\sqrt{n!}$ which is significantly bigger than the former case. Also the Schur polynomial grows different and then the peak of probability could move to the partitions with more parts, and partitions that do not resemble the spectrum of ρ. Therefore, is not clear how the probabilities behave in an infinite dimensional Hilbert space, and how the Keyl-Werner theorem should be generalized. We show some analytic exploration done when the spectrum of ρ decreases exponentially, and some numerical exploration done for some other spectra.

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Keywords: quantum information and entanglement
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7.9 Entanglement structures in the fractional quantum Hall effect

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Abstract

The study of the Fractional Quantum Hall Effect (FQHE) discovered in 1982 by Tsui, Stormer and Gossard [4] has been enlightening in various fields of Physics. Particullarily, in the past two decades this effect has been of major interest for the study of highly correlated systems entanglement. In this work, I will present the main results obtained by Haque, Zozulya, Schoutens [1], Levin and Wen [3] in this field, illustrating how the FQHE exhibits entanglement and in particular, how it exhibits the well known topological entanglement entropy [2]. The topological entanglement entropy will be studied in spherical geometry and in the common toroidal geometry, which arises naturally from the problem. As a complement to the study, a full

study of the entanglement spectrum will be provided for several values of the filling factor, ν, considering a FQHE with Coulomb interaction.

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[4] D. C. Tsui, H. L. Stormer, and A. C. Gossard. Two-dimensional magnetotransport in the extreme quantum limit. Phys. Rev. Lett., 48(22):1559-1562, May 1982.

Keywords: Entanglement, Topological Entanglement
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7.10 Schmidt coefficients distribution of random pure states of indistinguishable particles

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Abstract

For bipartite systems, the Schmidt decomposition gives all the information about the entanglement of the system, the behavior of the distribution of these coefficients for random (distinguishable particles) pure states is well known in the literature. In this work we study the distribution of the fermionic and bosonic Schmidt coefficients for indistinguishable particles random pure states; we provide analytic as well as numerical results and point out how the particle's statistics account for the differences between the entanglement in these cases and the distinguishable particles case.

Keywords: quantum information, computation, decoherence, and entanglement E-mail: `clviviescasr@unal.edu.co`

7.11 Measurement of 1-qubit operations on single photons

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Abstract

An experiment to apply single qubit operations is implemented, using the polarization of a single photon as information carrier. Heralded single photons ensure uniqueness of used particles. Measurements are done in three different quantum bases.

Experimental Procedure

Polarization is the most accessible quantum property of single photons. For this reason working with this property for implementing quantum information systems is likely pursued. We focused in implementing arbitrary single qubit operations, since it is one of the two requirements to process information quantumly (the other being a c-not implementation).For the present experiment, two complementary setups were required, as shown in figure 1. The first, known as an " heralded single photon source", is composed of a 405nm laser impinging a nonlinear Beta-Barium Borate (BBO) crystal cut to produce 810nm horizontally polarized two-photon pairs via type I spontaneous parametric down conversion (SPDC); produced photons are called signal and idler. The signal photon helps to herald the idler photon after the operation, measuring the coincidences between them.The second setup measures one of the photons (e.g. idler), which is operated previously by an arbitrary set of optical waveplates, modifying its polarization state. Applied operations correspond to the effect of the photon passing through rotated half and quarter waveplates. Measurements are done in three different bases by using a polarizing beamsplitter and appropriate waveplates; selected bases are horizontal/vertical ($|H\rangle$ and $|V\rangle$), diagonal/anti-diagonal($|D\rangle$ and $|A\rangle$) and left circular/right circular ($|L\rangle$ and $|R\rangle$).

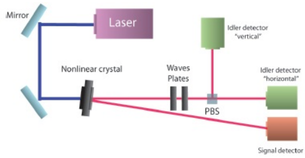

Fig 1. Assembly

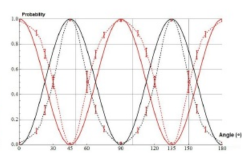

Fig 2. Half wave plate

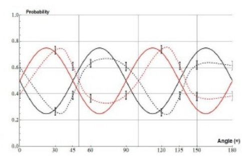

Fig 3. Quarter wave plate

Quantum operation given by rotating a half waveplate and a quarter waveplate. Measurements in $|H\rangle$ and $|V\rangle$ basis and $|D\rangle$ and $|A\rangle$ basis, respectively. In the figure 2, the red curve represents the state $|H\rangle$, while the black curve represents the state $|V\rangle$. In the figure 3,the red curve represents the state $|D\rangle$, while the black curve represents the state $|A\rangle$. Continuous (Dashed) curve correspond to theoretical (measured) data.

Results

Obtained results show the probability that the photon collapse into one of two orthonormal states of the corresponding base; at the same time, the comparison with theoretical data serves as proof of the normalization and superposition properties of qubits, primordial characteristics for quantum computing systems. For each operation waveplate (half and quarter) the output state was measured during 3 minutes per measurement basis. A sample of the obtained probability measurements are depicted in figures 2 and 3. The outcomes show a behavior that can be explained theoretically by using the matrix representation associated to each waveplate with good accuracy. This experiment has been admitted to take part of the regular experiments offered within the Quantum Optics course at Physics Department, Universidad de Los Andes.

Keywords: quantum information, optical processing, polarization. df.urrego1720@uniandes.edu.co

7.12 Characterizing a heralded single-photon source

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Abstract

Currently, spontaneous parametric down-conversion (SPDC) is used as one of the more convenient methods to generate single-photons, namely, heralded single-photons (HSPSs)[1, 2, 3]. This name derives from the fact that one of photons produced by SPDC can be used to announce the presence of the other. In this work, we characterize the theoretical and experimental aspects of a HSPS. We derive expressions for the second-order correlation function, $g^{(2)}(\tau)$, in terms of parameters that can be controlled in the laboratory, taking into account the effect of the electronic and detector jitter in this kind of measurements. The experimental setup is shown in figure. 1. We measure the correlation function, $g^{(2)}(\tau)$, for the HSPS by using three-fold coincidences. The experimental results are in agreement with the theoretical predictions.

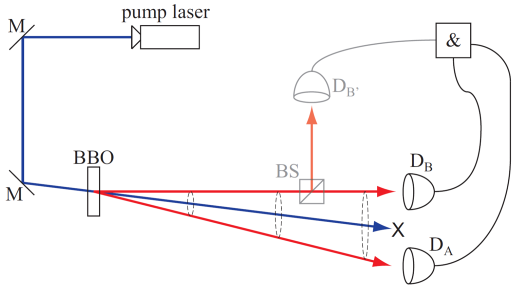

Figure 1: Single-photon source setup. A pump laser passes through a BBO crystal cut to produce biphotons via type-ISPDC. For the single photon $g^{(2)}(\tau)$ measurement, a beam-splitter and third detector are placed. One of the SPDC photons goes to detector A, heralding the arrival of its pairedSPDC photon in detectors B or B'.

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Keywords: Photon statistics, Parametric processes, Single-photon source and antibunching o.calderon31@uniandes.e

8 Contributed Posters:

8.1 Quantum Darwinism in scattered photons

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Abstract

The existence of the so-called "Quantum Darwinism", the encoding of redundant information of a system in decoherence by its environment, is studied for a macroscopic object illuminated by a blackbody. The quantum mutual information for a system comprised by a dielectric sphere in a photon environment is calculated for an arbitrary source over a unit sphere section. The dependence of the production of redundant information on the source's shape is shown, a fundamental requirement for the production of classical robust states, and so, a proposed reason for the emergence of the classical reality from the quantum one. Furthermore, large decoherence times for this type of systems, under real environmental conditions, are reported. This implies a huge redundancy even by environments that don't favor its production.
Keywords: Quantum mutual information, decoherence, quantum Darwinism

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8.2 A generalized quantum game structure: the role of correlations

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Abstract

During the last decade the introduction of game theory in a quantum domain has promoted the development of alternative algebraic tools, which reveal some advantages at solving dilemmas and optimizing profits beyond the usual interaction description between agents provided by the classical model. These results have been achieved thanks to the use of quantum attributes such as superposition and entanglement between quantum states.

In this work, a generalized quantization scheme for bipartite games is introduced, and corrections to a previous protocol reported in [1] are indicated. The scheme here developed correctly reduces to the well-known quantum treatments of Eisert [2] and Marinatto [3]. Within the context of the quantum Prisoner's dilemma, the role of quantum correlations followed by the input game strategy is described. In this way, correlations can be identified as properties of the physical system that embody the interaction between quantum agents, a fact that is found to be associated to the advantage of the quantum representation over the classical one. The results indicate that entanglement is not the only feature that backs the quantum advantage, and that the latter could take place even in its absence. An experimental set-up to test this quantum gain for the case of a non-zero sum game is discussed.

Keywords: Game theory, quantum bipartite games, quantum correlations, entanglement.

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8.3 Influence of quantum coherence on the efficiency of a photovoltaic solar cell

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Abstract

Solar cells are semiconductor devices that make possible to transform the direct solar radiation into electrical energy. This energy production occurs when photons interact with the semiconductor which has a forbidden energy gap (E_g), which is at a much lower temperature of ∼300K. Photons with energy $\hbar\omega \geqslant E_g$ are absorbed while those with $\hbar\omega < E_g$ are not. Thus, photogenerated electrons are routed through a load as electrical energy. Efficiency of

photovoltaic solar cell has been studied from different approaches in recent years. In 1959, Scovil and Schulz-DuBois [1] used detailed balance concepts to show that maser photons were produced with Carnot quantum efficiency. Subsequently, Shockley and Queisser [2] used detailed balance to find the upper limit of efficiency of photocell iluminated with thermal light. Moreover, efficiency depends on the radiative recombination where the excited electrons are carried to the ground state, so that radiatively induced quantum coherence can break detailed balance and yield lasing without inversion [3]. Our purpose is to demonstrate that it is possible to break the detailed balance in a solar cell with quantum efficiency $eV/\hbar\nu_s = \eta_c + \delta\eta$, where $\delta\eta$ is a model dependent increase in efficiency. In this paper, we show that the power delivered to the load is greather for a three-level system with Fano coupling and hence *noise-induced coherence* allows to interrupt detailed balance and obtain more power out of photovoltaic solar cell.[Fig. 1].

Keywords: quantum information, coherence, decoherence, and solar photovoltaic cells.

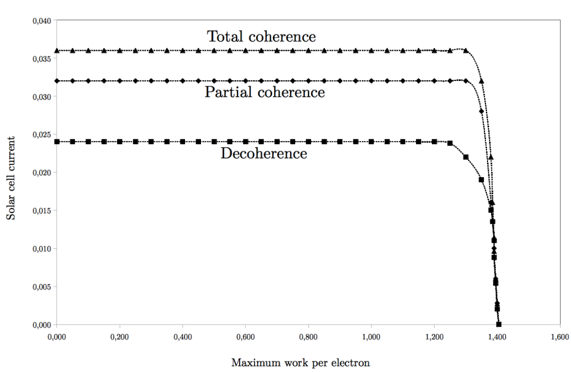

Figure 1. Solar cell current $j = \Gamma\rho_{\alpha\alpha}$(Photon flux $P_1/\hbar_{\nu 1}$)

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8.4 Relativistic dynamical quantum non-locality

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Abstract

In nonrelativistic quantum mechanics, quantum correlations are largely thought to be absolute. However, when they are studied in the framework of relativistic quantum mechanics, it is evident that they dependent highly on the reference frame [**?**]. In particular, two particles could be entangled in one reference frame but unentangled in a second one, thus quantum non-locality depends upon the reference frame.

In a accompanying poster, "Dynamical Quantum Non-locality", the non-locality of quantum dynamics was tracked, by working to the Weyl's representation of quantum mechanics, to the superposition principle. This is a kind of single particle non-locality, of different nature as the discussed above [4]. Here, we extend this work to the relativistic framework of quantum mechanics. In doing so, we review the current formulations of the relativistic Weyl's formalism and discuss the construction of the phase-space path-integral representation of the Wigner function as well as the influence of the reference frame on this dynamical quantum non-locality.

Keywords: Dynamical non-locality, path integrals, Wigner function

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8.5 Non-Markovian effects in the decoherence and entanglement between two different resonators

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Abstract

In the past years, some quantum phenomena have been observed at macroscopic scales. In particular, superconductivity, coherent superpositions of Bose-Einstein condensates and interference patterns in fullerenes have been detected. This fact has made that the border between the quantum and classical realms become more diffuse and intricate, although, more interesting, than before.

However, in order to observe these quantum features, one needs to reach the low temperature regime, $\hbar\omega/k_{\mathrm{B}}T \gg 1$, where $\hbar\omega$ denotes a characteristic system energy-scale and $k_{\mathrm{B}}T$ the thermal energy. Therefore, some delicate and elaborate cooling processes have been developed. Our work aims to show that, even, in the the high temperature regime, some quantum features such entanglement can be present, if the system is placed out from equilibrium. In particular, we study the non-Markovian dynamic of two different harmonic oscillators coupled to different baths at different temperatures and with different coupling-to-the-bath-strengths. We found that, despite the absence of symmetries in the parameters space, entanglement between the oscillators can be created and maintained in the long-time regime. We also discuss the implementation of our setup for studying the influence of the non-Markovian dynamics in the optimal sideband cooling of nano-mechanical resonators.

Keywords: quantum information, computation, decoherence, and entanglement

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8.6 Canonical typicality deviations in quantum mechanical nanoresonators

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Abstract

A longstanding result in statistical mechanics is the fact that physical systems *typically* thermalizes into a state that is well characterized by the canonical Boltzmann distribution. This result is usually derived under the assumption of weak coupling between the system of interest and the environment. Here we argue that in order to reach the canonical distribution, the high temperature condition also needs to be considered and therefore, deviations in the low temperature regime are expected. In the context of quantum mechanical nanoresonators, where the *effective* temperature is already of the order of nano-Kelvin, deviations from the canonical distribution come along with a new *true quantum* source of squeezing.

Keywords: canonical typicality, squeezing, weak coupling, nanoresonators.
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8.7 Photoluminescence of multiple quantum dots in a microcavity

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Abstract

We attempt to give a full quantum–mechanical explanation of the different regimes in the photoluminescence properties, observed in current experiments in quantum dots embedded in semiconductor microcavities. This matter–light system is modelled by a master equation whose unitary dynamics follows from the Dicke Hamiltonian ($\hbar = 1$)

$$\hat{H} = \omega_C \hat{a}^\dagger \hat{a} + (\omega_C - \Delta) \sum_i \hat{\sigma}_i^\dagger \hat{\sigma}_i + g \left(\hat{a} \sum_i \hat{\sigma}_i^\dagger + \hat{a}^\dagger \sum_i \hat{\sigma}_i \right), \quad (1)$$

where ω_C is the frequency of the quantized electromagnetic mode of the cavity, the detuning Δ is the difference between cavity mode and exciton energies, g is the matter–light coupling constant, $\hat{\sigma}_i$ is the ladder operator of the i–th exciton, and $\hat{a}^\dagger$ ($\hat{a}$) is the usual creation (annihilation) operator of the cavity mode. Note that the elementary radiators are assumed to be identical. The dynamics of the matter–light state operator is described by the Born–Markov master equation

$$\begin{aligned} \frac{\mathrm{d}\hat{\rho}}{\mathrm{d}t} = \mathrm{i}[\hat{\rho}, \hat{H}] \quad &+ \quad \frac{\kappa}{2}(2\hat{a}\hat{\rho}\hat{a}^\dagger - \hat{a}^\dagger\hat{a}\hat{\rho} - \hat{\rho}\hat{a}^\dagger\hat{a}) \\ &+ \quad \frac{P}{2} \sum_i \left(2\hat{\sigma}_i^\dagger \hat{\rho} \hat{\sigma}_i - \hat{\sigma}_i \hat{\sigma}_i^\dagger \hat{\rho} - \hat{\rho} \hat{\sigma}_i \hat{\sigma}_i^\dagger \right), \end{aligned}$$

where the second term of the r.h.s. stands for the cavity loses and the third one stands for the exciton pumping.

Our results, which allow us to establish the thresholds between the regimes, show that polariton and photon laser regimes critically depend on the quantum state of the system, as described by entanglement and mixedness, and by the second and third order correlation functions of emitted light.

Keywords: decoherence, entanglement
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8.8 State and tunneling control of ultracold bosonic atoms

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Abstract

We consider two bosonic atoms trapped in a double well potential. Assuming low energies, the atoms are assumed to populate the states with the lowest energies. Moreover, the atom-atom interaction can be approximated by a delta-function potential under these conditions.

This short-range interaction can be made time-varying by a proper experimental set up. We show that different variations can provide either state control, forcing the state of the system to be a particular state, or tunneling control, changing the tunneling rate. In the extreme case, coherent destruction of tunneling is produced.

Keywords: quantum coherence.
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8.9 Detuning control of qubit-qutrit entanglement in semiconductor microcavities

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Abstract

Manipulation of entanglement is one of the most important tasks in quantum information technologies. The usual schemes assume information storage in matter and information transmission by radiation. The electromagnetic field is also used to control the matter state, especially in cavity quantum electrodynamical systems. We consider a semiconductor microstructure, where a two–level (states $|G_1\rangle$ and $|X\rangle$) and a three–level (states $|G_2\rangle$, $|X_-\rangle$ and $|X_+\rangle$) matter systems interact with two electromagnetic cavity modes, with frequencies ω_1 and ω_2. The Hamiltonian of the system, in the dipole and rotating wave approximations, is ($\hbar = 1$)

$$\begin{aligned} H &= \omega_1 a_1^\dagger a_1 + \omega_2 a_2^\dagger a_2 + \omega_+ |X\rangle\langle X| + \omega_+ |X_+\rangle\langle X_+| \\ &+\omega_- |X_-\rangle\langle X_-| + g_1 a_1 |X\rangle\langle G_1| + g_1 a_1^\dagger |G_1\rangle\langle X| \\ &+g_1 a_1 |X_+\rangle\langle G_2| + g_1 a_1^\dagger |G_2\rangle\langle X_+| + g_2 a_2 |X_-\rangle\langle G_2| \\ &+g_2 a_2^\dagger |G_2\rangle\langle X_-| , \end{aligned} \tag{2}$$

where g_1 (g_2) and $a_1^\dagger$ ($a_2^\dagger$) are the coupling constant and the creation operator of the first (second) mode. The detuning $\Delta_1 = \omega_1 - \omega_+$ is assumed to be equal to $\Delta_2 = \omega_2 - \omega_-$.

We calculate the dynamics of the qubit–qutrit entanglement using the master equation for the matter–light state operator ρ, $\dot{\rho} = i[\rho, H] + \mathcal{L}(\rho)$ where Born and Markov approximations have been assumed. The non-unitary effects, described by $\mathcal{L}(\rho)$, include cavity losses, spontaneous emission and incoherent pumping to matter excited states.

Qubit–qutrit entanglement, as quantified by negativity, is calculated for unitary and dissipative dynamics. Our results show sudden death and revivals of the entanglement in both cases. We demostrate that with a proper choice of the parameters —particularly the detuning, it is possible to increase the time during which the matter partial state operator is entangled.

Keywords: entanglement, decoherence.
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8.10 Electronic transport and quantum entanglement in double quantum dots

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Abstract

We investigate the relationship between electron–electron entanglement and electron transport through two quantum dots coupled to metal leads. Each quantum dot has two energies in the range between the chemical potentials of the left and the right leads, $\{\varepsilon_1, \varepsilon_2\}$. The leads are considered as free electron gases at thermodynamic equilibrium. Since the quantum–dots system is allowed to exchange particles with the leads, the latter are described by grand canonical density matrices. Even more, it is assumed that the system–leads coupling is weak. The total state operator ρ_T at the initial time can be written as $\rho_T = \rho \otimes \rho_L$, where ρ and ρ_L are the system and leads state operators respectively. The dynamics of the density matrix ρ is obtained by solving a Markovian master equation up to second order in the system–leads coupling.

Keywords: decoherence, entanglement
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8.11 Dynamical quantum non-locality

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Abstract

Non-locality of correlations between systems is one of the hallmarks of quantum mechanics. Non-locality is responsible for unexpected features of system dynamics at the quantum regime such as tunnelling and entanglement; it has also recently been extensively exploited as a resource for quantum information [2]. The origin of non-locality of quantum measurements and its relations to the fundamental postulates of quantum mechanics, such as the uncertainty principle, have been only recently elucidated [3]. However, quantum interference problems involve two kind of non-localities: a non-locality expressed in terms of the Bell-inequalities (of kinematic nature, the one discussed in [3]) and the non-locality of the quantum equation of motion of a physical observable (of dynamic nature) [1, 4]. The latter has been barely discussed, explored or understood [4]. We trace here the origin of dynamical non-locality to the superposition principle mediated by the presence of non-linear interactions between systems and discuss the disappearance of non-locality in the classical realm. This relation adds to the more fundamental understanding of nature's quantum dynamics and allows us to establish and identify how the uncertainty principle and the superposition determine the non-local character of the outcome of quantum measurements. As a consequence, dynamical quantum non-locality emerges, naturally, as the responsi-

ble for the suppression of chaos, understood in the classical sense, in the quantum dynamics.

Keywords: Dynamical non-locality, path integrals, Wigner function

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8.12 A simple model for domain formation and hysteresis in magnetotransport in semiconductor superlattices

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Abstract

Since the experiments of Grahn *et. al.* (1) in highly doped superlattices (SL) in the presence of an electric field applied in the direction of growth, the appearance of field domains (FDs) has been extensively discussed. With an additional quantizing magnetic field, simultaneously perpendicular to the electric field and the growth direction, the FDs disappear. In the present work, we develop a simple model based in the Tight Binding approximation, which considers the quantum transitions and uses a self consistent procedure to deal with the well subbands electron population equations and the Poisson equation. We obtain a quantitative explanation for the FDs formation and suppression by the electric and magnetic fields, respectively. Our formalism predicts hysteresis in both the current–voltage and in the magnetic field–voltage profiles. Finally, these dynamics have a qualitative evidence in the current– voltage profile of SL fabricated and characterized experimentally.

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8.13 Statistical properties of light emission for a system of two quantum dots interacting with a microcavity

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Abstract

We present a study of statistical properties of light emission in a system of two quantum dots interacting with each other and also with the photons of a microcavity, we consider loss of photons through the microcavity mirrors and exciton pumping to the quantum dots. The interaction between quantum dots is modelled using the Von Förster Hamiltonian and in the radiation-matter interaction we consider the dipolar approximation and the rotating wave approximation. Using the master equation formalism we find the solution for stationary state and we calculate $g^{(1)}$ and $g^{(2)}$ on the light partial state operator to determine the light's statistical behavior in function of the coupling between dots, detuning, quality of the microcavity and pumping.

Keywords: quantum optics.
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8.14 Production of quantum random numbers

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Abstract

Using a qubit system, we are able to get random number sequences. Tests for statistical randomness are applied to each generated sequence. A truly random sequence comes from quantum events, while any other sequences don't show a real random behavior. The sequence from a classical event (or a computational program) can determine the next bit if a part of the sequence is known, because all classical events can described given that all parameters are known; these sequences are called pseudorandom sequences. On the other hand, a sequence coming from an event described by quantum mechanics hasn't a deterministic behavior, the output of the experiment can't be fixed, so even if one bit of the sequence is known, it is not possible to know the next bit.

In our experiment we use a standard assembly (similar to [1]) using three different sources of photons in order to get 3 different sequences with different parameters. We used an inexpensive laser of 650nm (as a standard assembly) for the first sequence; the second sequence comes from the same laser but using a rotating acrylic plate as a dispersion source and the third sequence comes from a red LED. In the experiment the photons are guided by two mirrors until they arrived to a beam splitting stage. Here photons arrive to a Polarizing Beam Splitter (PBS) after passing through an adjustable waveplate, in order to obtain a 50%

transmission (reflection); the input photon has two output paths. The source photon has a predefined polarization, which is the key to the PBS working as a controllable 50-50 beamsplitter. Then, the user must decide if a detection of a vertical (reflected) photon will be a logical one and a horizontal (transmitted) photon will be a logical zero or vice versa. Obtained sequences in our setup are about 300000 bits long for each case, and takes about 5 hours to obtain them.

There are a few algorithms to test if a sequence is random or not [2]. Most of them give a p value as a result, that says the sequence would be considered as random (non random) if $p > 0.01$ ($p < 0.01$) with a confidence of 99%. A potential improvement to the experiment is to get longer sequences, which potentially can get a better p value.

Keywords: Quantum information and processing, Photon counting, Randomness, PBS.

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8.15 Measurement of 1-qubit operations on single photons

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Abstract

An experiment to apply single qubit operations is implemented, using the polarization of a single photon as information carrier. Heralded single photons ensure uniqueness of used particles. Measurements are done in three different quantum bases.

Keywords: quantum information, optical processing, polarization.

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8.16 Dynamics of a microcavity-quantum dot system: beyond the excitonic regime

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Abstract

The development of techniques for the fabrication of solid state nanostructures and the theoretical description of them

have allowed the construction of artificial atoms embedded in semiconductor optical microcavities, systems which present strong coupling between the electromagnetic field and the matter, with many technological applications, like one-photon sources, polaritonic condensates, quantum cryptography, quantum teletransportation and solid state lasers.

In this work, we study the Hamiltonian and dissipative dynamics of a quantum dot embedded in an optical microcavity, in such a way that electron-hole pairs density is high enough to allow the quantum dot to be occupied by two excitons. When those excitons interact, a quasiparticle named biexciton is created. The interest in biexcitonic systems has increased in the last years because they can be sources of entangled photons, that allow us apply them in quantum information processing tasks. We model the quantum dot as a four level system strongly coupled to two degenerate modes of the optical cavity. For the theoretical treatment of the system, we use the formalism of the Liouville-Von Neumann equation in the Hamiltonian case and the master equation -Born and Markov approximations- in the dissipative case. In the Hamiltonian case, we solve the Liouville-Von Neumann equation for two initial conditions of the field: Fock states and coherent states. In the first case, the populations effectuate Rabi oscillations; in the second one, some population inversions exhibit collapses and revivals, while others oscillate harmonically after a short transitory state of complex behaviour. The non conservative processes considered are the loss of photons from the microcavity and the continuous pumping of excitons by an external laser. We make a comparative analysis of population evolution and entanglement for the states, between the Hamiltonian and the dissipative cases, and determine the effects of dissipation on quantum mechanical properties of the system.

Keywords: biexciton, quantum dots, optical microcavities, dissipation, exciton pumping and entanglement
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8.17 Distinguishing topological phases using the entanglement spectrum

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Abstract

Topological order is a characterization of certain states of matter that cannot be described using local order parameters but rather by non-local observables connected to topological invariants. Given its non-local character, the concept of entanglement from quantum information theory, has become useful to study topological order. An important realization of topologically ordered states ocurrs in the Fractional Quantum Hall Effect (FQHE) ground states. For each filling factor, the trial function presents a different topological order. For a FQHE model function $|\psi\rangle$, we define the density matrix $\rho = |\psi\rangle\langle\psi|$. The reduced density matrix $\rho_A = \mathbf{Tr}_B\rho$, given a bipartition of the system in the subsystems A and B, can be written as $\rho_A = e^{-H}$, and the so-called Entanglement Spectrum (ES) is defined as the spectrum of H. The ES provides a finer characterization of the entanglement between two regions, as compared to the entanglement entropy, and is a useful tool in detecting topological order. We present the ES for some ground state trial functions for the FQHE, and the information that can

be obtained from it, as a means of detecting different topological phases.

Keywords: quantum information, computation, decoherence, and entanglement.

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8.18 On the dynamics of spin-$\frac{1}{2}$ particles: A Phase-space path-integral approach

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Abstract

The two-level quantum system is the most fundamental element in quantum-information-processing theory (QIPT) and one of its more natural physical implementations comprises a spin-$\frac{1}{2}$-system. Entangling these systems and their subsequence manipulation, base on the non-local character of quantum correlations, are the most fundamental protocols in QIPT. The non-locality that is exploited in those protocols is a non-locality between quantum systems; however, in order to get a complete picture of the quantum correlations time-evolution, one has to analyze the influence of the non-local character of the quantum dynamics itself (dynamical non-locality).

In two accompanying posters on dynamical quantum non-locality, "Dynamical Quantum Non-locality" and "Relativistic Dynamical Quantum Non-locality", it is discussed

how the analysis of this non-locality benefits from the phase-space representation of quantum dynamics. Motivated by those results, here we construct the phase-space path integral approach to the dynamics of spin-$\frac{1}{2}$ systems. In doing so, we derive a unified picture of the phase-space representation of systems with finite-dimensional Hilbert space (1) and the path-integral approach for the unitary time-evolution operator (2).