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CEWQO2009

THE 16th CENTRAL EUROPEAN WORKSHOP ON QUANTUM OPTICS

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Edited by Kari Härkönen, Sabrina Maniscalco, Jyrki Piilo,
Kalle-Antti Suominen and Otto Vainio

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Preface

The Central European Workshop on Quantum Optics has grown over the years from a modest regional workshop into an annual conference with about 150 participants, and the length of five full and eventful days. At the same time the locations for the event have drifted to cover a wide geographical range, from Turkey to Sicily, and now even to Finland, which is very definitely in Northern Europe.

This expansion can be partly attributed to the widening of the field of quantum optics, with cold atomic gases and quantum information science emerging as strongly related fashionable fields. Also the expansion of the European Union and its research funding programmes have increased the mobility of researchers in Europe. The increase and widening of the research activity, however, emphasises the need for a *quantum optics* conference, and the CEWQO series fulfills this purpose exactly.

The physicists at the University of Turku have the honour to organise the 16th Workshop, or CEWQO2009. We are pleased that so many people have registered as participants, and we hope that everyone can enjoy both the scientific as well as the social program of the meeting, including the boat cruise on Monday 25th, where work can be combined with pleasure, as lectures on that day take place while we journey through the archipelago of the South-Western Finland. It should be remembered that exactly 200 years ago, although a bit earlier in the winter, when it was still possible to travel on ice, the last Swedish troops left Finland along this route, and the local history changed drastically.

In addition to this book of abstracts, the actual proceedings of CEWQO2009 will be published in Physica Scripta, a journal governed by Nordic Scientific Academies and Physical Societies. For this I wish to express thanks to prof. Roger Wäppling. Special thanks go to all the members of the Quantum Optics group, and the staff of the Turku University Congress Office. We also thank the Federation of the Finnish Learned Societies (TSV) and Turku University Foundation for financial support.

Finally, I wish to congratulate prof. Stig Stenholm, who had his 70th birthday in February 2009. In practice he is the founder of the laser physics and quantum optics activity in Finland. We shall celebrate this on May 26th with a specially selected group of lecturers, including Stig himself.

Kalle-Antti Suominen
Chairman of CEWQO2009

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Invited Speakers

ANCILLA-DRIVEN QUANTUM MEASUREMENT AND COMPUTATION

Erika Andersson[1], Janet Anders[2], Dan Browne[2], Elham Kashefi[3] and Daniel Oi[4]

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Generalised quantum measurements (positive operator valued measures, POVMs, or probability operator measures, POMs) are important for optimally extracting information for quantum communication and computation. If a quantum system undergoes unitary evolution, and we trace out part of it, then the evolution of the remaining part will be described by a completely positive map. Conversely, any completely positive map may be implemented by unitary evolution in an extended Hilbert space. Any generalised quantum measurement can, much in the same way, be implemented by a unitary projection in a higher-dimensional Hilbert space. That is, the system to be measured plus an ancillary system undergoes unitary evolution, and then both original and ancillary systems are projectively measured. Moreover, we can limit the dimension of the ancillary system to less than what one would think is necessary. For any measurement, it is possible to construct a binary search tree with a depth logarithmic in the number of possible outcomes [1]. This could be realised experimentally by coupling the measured quantum system to a probe qubit which is measured, and then iterating.

These ideas for simple implementation of quantum measurements can be combined with concepts from measurement-based quantum computation, giving us ancilla-driven quantum computation (ADQC) [2]. ADQC includes aspects of both circuit-based quantum computation and measurement-based computation. Instead of directly manipulating qubits to perform universal quantum logic gates or measurements, ADQC uses a fixed two-qubit interaction to couple the memory register of a quantum computer to an ancillary qubit. By measuring the ancilla, the measurement-induced back-action on the system performs the desired logical operations. No interactions between ancillary qubits is needed; after it has interacted with system qubits once and been measured, an ancillary qubit may be discarded, or reset and reused. This simplifies experimental realisation and makes highly parallel computation possible.

[1] E. Andersson and D. K. L. Oi, Phys. Rev. A **77**, 052104 (2008).
[2] E. Kashefi, D. K. L. Oi, D. Browne, J. Anders, and E. Andersson, to appear in the proceedings of the 25$^{\text{th}}$ Conference on the Mathematical Foundations of Programming Semantics, University of Oxford, April 3 - 7, 2009.

NON-MARKOVIAN QUANTUM TRANSPORT AND RELAXATION

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Realistic quantum mechanical systems are influenced through the coupling to an environment containing a large number of mostly uncontrollable degrees of freedom. This unavoidable interaction of an open quantum systems with its environment leads to the mechanisms of dissipation and damping, and to a strong and often rapid loss of quantum coherence. The talk begins with a brief introduction into the standard theory of quantum mechanical relaxation which is based on the Markov approximation and on the concepts of completely positive dynamical semigroups and of quantum master equations in Lindblad form. Many examples for this approach are known from quantum optics, decoherence theory, quantum Brownian motion and quantum measurement and control theory. However, strong couplings or interactions with low-temperature reservoirs generally lead to large system-environment correlations which result in long memory times and in a failure of the Markov approximation. To describe the basic features of the non-Markovian quantum dynamics of open systems we develop several new methods as, for example, the technique of correlated projection superoperators [1] and the concept of quantum semi-Markov processes [2]. A number of examples and applications to structured reservoirs [3], to electron spin dynamics in quantum dots [4], and to the problem of quantum transport in nano-structures [5] will be discussed.

[1] H. P. Breuer, Phys. Rev. A 75, 022103 (2007).
[2] H. P. Breuer and B. Vacchini, Phys. Rev. Lett. 101, 140402 (2008).
[3] H. P. Breuer, J. Gemmer and M. Michel, Phys. Rev. E 73, 016139 (2006).
[4] E. Ferraro, H. P. Breuer, A. Napoli, M. A. Jivulescu, and A. Messina, Phys. Rev. B 78, 064309 (2008).
[5] R. Steinigeweg, H. P. Breuer and J. Gemmer, Phys. Rev. Lett. 99, 150601 (2007).

QUANTUM MECHANICS AS A FRAMEWORK FOR DEALING WITH UNCERTAINTY

Paul Busch

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In this lecture I will argue that *uncertainty* is a key concept for the characterisation of the fundamental differences between quantum theory and classical probabilistic theories. To this end I will review a recent theorem on the generic forms of classical extensions of quantum probability theory, which renders the latter in an essentially unique way as a theory of classical fuzzy random variables.

I will also survey various ways of making precise the broad idea of quantum uncertainty through formalizations of terms such as *indeterminacy*, *inaccuracy*, *unsharpness*, and *measurement disturbance*, and discuss some examples of novel applications of quantum structures to show how they can be understood as ways of trading one form of quantum uncertainty for another.

OPTOMECHANICAL COUPLING IN A ONE-DIMENSIONAL OPTICAL LATTICE

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In this talk I will present a one-dimensional scattering model to describe collective phenomena in optical lattices. In recent papers [1,2] we have shown that traveling density wavelike collective oscillations can arise in an asymmetrically pumped optical lattice, and by increasing the lattice size or pump asymmetry, these waves can destabilize the structure even in the overdamped limit. The long-range interaction giving rise to collective motion stems from the back-action of the atoms on the field creating the lattice. I will derive the force on a disk-shaped cloud of trapped particles including the back-action on the trapping light, and analyze its relation to the standard perturbative approach giving the "dipole force" and "radiation pressure." I will calculate the self-consistent lattice constant for both red and blue detuned lattices and find that it decreases – by the same amount in the two cases – as the pump asymmetry is increased. I will present the detailed derivation of the lattice vibration eigenmodes using the transfer matrix method, which reveals that the instability is enhanced resonantly at certain settings of the asymmetry. Finally, I will discuss some aspects of the "ultrastrong coupling" regime of cavity QED, in particular, the consequences of the lack of a dipole potential to derive forces in an opto-mechanically coupled system [3].

[1] J. K. Asbóth, H. Ritsch, P. Domokos, Phys. Rev. Lett. 98, 203008 (2007)
[2] J. K. Asbóth, H. Ritsch, P. Domokos, Phys. Rev. A 77, 063424 (2008)
[3] J. K. Asbóth, P. Domokos, Phys. Rev. A 76, 057801 (2007)

QUANTUM ZENO EFFECT AND QUANTUM FEEDBACK IN CAVITY QED

I. Dotsenko, J. Bernu, S. Deléglise, C. Sayrin, M. Brune, J.-M. Raimond, S. Haroche, M. Mirrahimi and P. Rouchon

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Any measurement perform on a quantum system produces an unavoidable backaction on its state. Being well controlled a quantum measurement can not only project the system's state onto an arbitrary eigenstate of the corresponding measurement operator, but also be used to influence the system's evolution. We investigate these effects experimentally by using a quantum nondemolition (QND) measurement of the number of photons in a field, trapped in a high-quality microwave cavity [1]. For this purpose, the cavity field is probed by a stream of non-absorbing circular Rydberg atoms acting as quantum probes of light. Combining the QND measurement with coherent microwave injection into the cavity, we first demonstrate quantum Zeno effect. By repeatedly injecting tiny coherent pulses into the cavity mode, we observe the coherent growth of the field amplitude. This evolution is dramatically inhibited by a repeated measurement of the photon number performed between injections. This freezing of the coherent field evolution illustrates the backaction of the photon number determination onto the field phase, which becomes completely diffused after one photon-number measurement, thus making impossible the coherent addition of a subsequent injection pulse [2].

The QND photon counting performed on an initial coherent field prepares a random photon number (Fock) state of light. We propose an active quantum feedback scheme to deterministically generate desired Fock states and to protect them against decay. Within a feedback loop, detection of each individual atom provides us information on the current state of the field. We steer it towards a desired state by injecting into the cavity a coherent pulse adjusted to increase the population of the desired photon number and to guarantee the convergence of the field towards the desired state after several tens feedback cycles. Keeping the procedure active after convergence will maintain the field in this Fock state, restoring it after each decoherence-induced quantum jump. The efficiency and reliability of the closed-loop state stabilization is illustrated by results of quantum Monte-Carlo simulations.

[1] C. Guerlin *et al.*, Nature 448, 889 (2007).
[2] J. Bernu *et al.*, Phys. Rev. Lett. 101, 180402 (2008).

MEASURING MARKOVIANITY
and other topics of systems identification in quantum optics and quantum information

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In this talk, we will pose the question of how one can systematically assess dynamical properties of quantum optical systems, some of which may appear difficult to be measured or even unmeasurable. The paradigm followed is to only make use of measured data and not to resort to any uncertified and possibly unjustified a priori assumptions - but to make the most out of these very same data [1,2,3,4]. We consider the question of how to measure environmental properties like spectral densities of phonon environments of optomechanical systems and discuss how this relates to measuring non-Markovian dynamics of micromirrors [2], in joint theoretical and experimental work. We also ask how one can decide whether a given time evolution is Markovian from a single snapshot in time [3], and show how processes can be tomographically assessed with high probability using only slightly more than linearly many data points instead of quadratically many, using new ideas of compressive sensing [4].

[1] J. Lundeen et al, Nature Physics **5**, 27 (2009).
[2] K. Kieling, A. Trubarov, S. Groeblacher, M. Aspelmeyer, J. Eisert, in preparation (2009).
[3] M.M. Wolf, J. Eisert, T. Cubitt, J.I. Cirac, Phys. Rev. Lett. **101**, 150402 (2008).
[4] S.T. Flammia, D. Gross, J. Eisert, in preparation (2009).

DRESSED RF ATOM TRAPPING

Barry M. Garraway

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Dressed rf trapping is a new technique for trapping and controlling cold atoms. For some time it has been possible to trap neutral atoms in optical dipole traps or in magnetic traps, but dressed rf traps use a combination of rf and static magnetic fields (with gravity). The rf with variable frequency, polarization, and detuning, in combination with with spatially varying magnetic fields offers new versatility in atom trapping.

The talk will include the theoretical conception of these traps, loading techniques, illustrations from some of the different experimental approaches and theoretical developments on trapping, cooling, and leakage.

QUANTUM MECHANICS OF IMAGE PROCESSING

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Principles of quantum information and quantum tomography will be applied to optics and image processing. Information retrieval will be illustrated on several examples of wave optics including the example of Hartmann - Schack sensor and aperture synthesis. The theory hinges upon the recently developed methods of objective quantum tomography. Adopting the formalism of quantum mechanics the problem of the measurement on demand will be formulated and illustrated on the example of vortex fields.

[1] Ježek M., Z. Hradil Z., *Reconstruction of spatial, phase and coherence properties of light*, J. Opt. Soc. Am. 21 (2004) 1407 -1416.
[2] Hradil Z, Mogilevtsev D, J. Řeháček, *Biased tomography schemes: An objective approach*, Phys. Rev. Lett. 96, 230401, 2006.

NONLINEAR PHENOMENOLOGY FROM QUANTUM MECHANICS

Juha Javanainen

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Quantum mechanics is widely accepted as the fundamental framework for physics. Nonetheless, a variety of nonlinear theories have met with unquestionable success in the modeling of macroscopic (many-body) systems. This state of affairs begs for the question of how linear quantum mechanics mimics nonlinear behavior. In this work we pursue the hypothesis that the nonlinear phenomenology is implicitly contained in the correlations in the quantum state of a many-body system, but it is ultimately the observations (measurements) that bring it out.

As an example, we have studied a soliton for bosonic atoms in an optical lattice when the interactions between the atoms are attractive. Classically, and experimentally, the ground state may be a soliton. A soliton is localized, and, being a result from a nonlinear theory, is not subject to the superposition principle; you cannot make a nonlocalized ground state by superimposing solitons. On the other hand, for the same situation quantum mechanics guarantees that the ground state is lattice-translation invariant, and cannot be localized.

To resolve this discrepancy, we have solved the ground state for reasonably large lattice models using a quantum Monte Carlo (QMC) method. It turns out that each individual sample configuration of the state of the lattice produced by our QMC algorithm is a faithful simulation of a single measurement of the occupation numbers of the atoms at the lattice sites. Since the sample configurations qualitatively and quantitatively closely resemble the classical solitons expected under the same conditions, our hypothesis about the role of measurements in nonlinear phenomena is validated in this example.

ASYMPTOTIC DYNAMICS OF INTERACTING QUBIT NETWORKS

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Networks of simple physical objects are universal tools used in many different branches of physics. In classical physics, for example, they are used to model complicated systems ranging from interacting simple particles to the dynamics of members of social communities. In all these cases network models are used to catch basic features of these physical systems.

The study of analogous models in quantum mechanics represents difficulties. In simplest cases we can imagine that the individual elements of a network are two-level systems (qubits) with simple interactions between them. The analytic treatment of such systems is not easy, in particular if the number of two-level systems involved is large because the system size grows exponentially with the number of two-level systems. This makes straightforward approaches intractable. However, if we limit ourselves to studies of the long-time asymptotic dynamics it becomes possible to obtain detailed results.

This talk presents first results on studies of ensembles of qubits whose interactions are simulated by random unitary transformations. We show that the long-time dynamics of such random unitary channels are determined completely by an attractor set formed by eigenvectors of the random unitary channels corresponding to eigenvalues of unit modulus. We show how the relevant eigenstates can be obtained from generalized commutation relations involving the Kraus operators defining the random unitary channel. After analyzing the general analytic form of the resulting asymptotic dynamics we discuss implications for a quantum network involving random controlled NOT operations as the mutual interactions between the qubits involved. Links to graph theory are pointed out.

PHOTONIC WIRING OF IONS

W. Lange, P. Blythe, E. Brama, D. Crick, M. Keller, A. Mortensen, A. Riley-Watson, N. Seymour-Smith, A. Wilson

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Ions confined in radio-frequency traps have been employed very successfully in quantum information processing, with a range of quantum gates and quantum algorithms now realized. One limitation of using ions is that the quantum information is available only locally. A significant gain is predicted from connecting multiple processing nodes through quantum channels, capable of distributing quantum states over long distances [1]. An obvious choice for these *quantum wires* are photons, which already serve as qubit-carriers in quantum communication. The principal challenge is to establish a coherent interface between photons and ions to reliably map quantum information between the two systems which interact only weakly in free space.

Strong coupling of single photons and *neutral* atoms has been achieved in cavity-QED. For *ions*, controlled emission of single photons was demonstrated in high-finesse cavities [2]. The technique can be extended to a quantum interface in two different regimes, both of which are presently being implemented at the University of Sussex. *Deterministic* state transfer is achieved by mapping the qubit state of an ion to a cavity photon with laser pulses. The photon is transferred to a distant cavity through an optical fibre link (Fig. 1), where its quantum state is reverse-mapped to another ion [1]. An important application is entanglement distribution in a quantum network. Entanglement may also be generated *probabilistically*, even if only weaker coupling is available. When a photon produced in a cavity containing *multiple* ions is detected (Fig. 2), the ions may be projected to an entangled state due to the lack of information which ion the photon originated from.

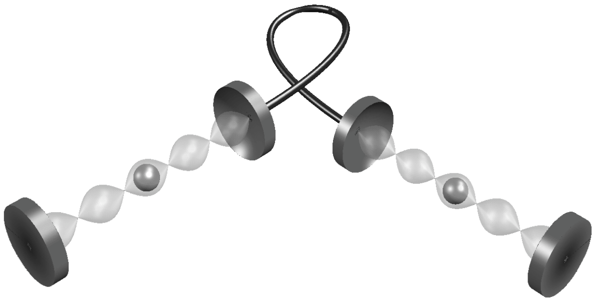

Figure 1: Setup for quantum networking with two ion-trap cavity-QED systems connected by a fibre-based photonic wire.

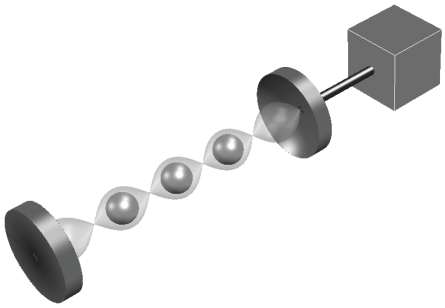

Figure 2: Ions coupled to a cavity whose output is monitored by a detector to yield probabilistic entanglement.

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[2] M. Keller, B. Lange, K. Hayasaka, W. Lange, H. Walther, Nature 431, 1075 (2004).

TOMOGRAPHIC PROBABILITY REPRESENTATION IN QUANTUM OPTICS AND POSSIBILITY OF EXPERIMENTAL CHECKING OF UNCERTAINTY RELATIONS

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The Schrödinger–Robertson uncertainty relation is formulated within the framework of the probability representation of quantum states. Possible experiments for checking the uncertainty relations, in view of homodyne measuring the photon quantum states, are discussed. Expressions of the measurable quantum characteristics of the states in terms of optical tomograms are obtained. A direct measurement of the purity parameter of a quantum state by measuring homodyne photon quadrature is considered. A possible experiment to measure the temperature of a thermal electromagnetic field state by a homodyne photon detector is reviewed. The measurement of photon statistics by means of measuring homodyne quadrature statistics is suggested. New inequalities which provide the difference between the classical and quantum electromagnetic field states are found.

ITERATIVE OPERATIONS ON QUANTUM SYSTEMS

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Generally speaking, frequent repetition of the same operation amplifies the effects induced by a single operation, which for a physical system results in applying the N-th power of the map corresponding to a single operation. In many applications in quantum mechanics this scenario is often realized exploiting repeated measurements performed on a system, hence adding the ingredient of non-unitarity. Depending on the kind of measurement and on the time evolution between two measurements, the process can either freeze the dynamics (quantum Zeno effect) or accelerate it (inverse Zeno effect) through modification of pre-existing decay channels and possible creation of new (artificial) ones. In the case of inverse Zeno effect, the decays effectively realize the filtration of the surviving quantum states, so that repeated measurements can be used to extract quantum states from an initial condition. I discuss these occurrences in different physical situations and show the connection between the outcomes, i.e. the states the system is eventually found into, and the operations performed, also taking into account the effects of the interaction with possible environmental degrees of freedom.

ENTANGLEMENT MANIPULATION VIA PURE AND MIXED STATES

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In quantifying quantum entanglement of two-qubit mixed states the following measures are commonly applied: the relative entropy of entanglement (REE) – a measure of a "distance" of an entangled state from the set of disentangled states, the (logarithmic) negativity – a measure of entanglement cost under operations preserving the positivity of partial transpose (PPT), the concurrence – a measure of the entanglement of formation, and the entanglement of distillation (ED) – a measure of the entanglement as the fraction of Bell states that can be distilled using the optimal purification protocol.

It is well known that the upper bounds of the REE for a given concurrence and of the negativity for a given concurrence are reached by pure states. So, one could conjecture that pure states have also the highest REE for a given negativity.

By contrast, we demonstrate that there are mixed states for which the REE and the ED for a given negativity ($\lesssim 0.5$) are higher than those for pure states. The point is that the (logarithmic) negativity is equal to a PPT entanglement cost for an exact preparation, REE is equal to a PPT distillable entanglement for pure states, and ED is a lower bound of a PPT distillable entanglement. So, our findings provide an explicit example of the PPT operations that, even though the entanglement cost for an exact preparation is the same, ED of a mixed state can exceed that of pure states. In other words, the entanglement manipulation via a pure state can result in a larger entanglement loss than that via a mixed state.

[1] A. Miranowicz, S. Ishizaka, B. Horst, A. Grudka, Phys. Rev. A **78**, 052308 (2008).
[2] A. Miranowicz and S. Ishizaka, Phys. Rev. A **78**, 032310 (2008).

QUANTIFICATION AND USE OF NONGAUSSIANITY IN QUANTUM OPTICS AND QUANTUM INFORMATION

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Continuous variable quantum information was born with Gaussian states and operations, which are extremal for many quantities of interest in theoretical quantum information and are easily generated in quantum optical systems, thus allowing the implementation of several quantum protocols, as for example teleportation, dense coding and cloning. On the other hand, it has been recently proved that those protocols may be improved upon exploiting the nonGaussian features of the radiation field. Besides, quantum information protocols required for long distance communication, as for example entanglement distillation and entanglement swapping, require nonG operations. Overall, nonGaussianity is revealing itself as a resource for continuous variable quantum information and its quantification thus represents a necessary step for the development of quantum technology.

In this talk we address the problem of quantifying the amount of nonGaussianity of a quantum states and suggest two quantities that fulfill the natural requirements expected from such a measure. The idea behind our measures is that of comparing the state under investigation with a reference Gaussian state, either using relative entropy or in term of a distance in the Hilbert space. We analyze the properties of the nonG measures and compare them with possible other proposals. The novel quantities may be evaluated for several families of quantum states and allow to assess nonG as a resource for quantum information. In particular, a necessary condition for the Gaussian character of a quantum channel has been derived. In addition, performances of both Gaussification (by loss or conditional measurements) and de-Gaussification (by Kerr interaction, photon addition/subtraction or phase diffusion) protocols may be assessed and compared. We have characterized maximally nonGaussian states at fixed energy and evaluated typical non-Gaussianity of finite superpositions. Finally, a sufficient condition for entanglement of bipartite states have been derived in terms of nonGaussianity.

[1] Marco G. Genoni, Matteo G. A. Paris, *Nongaussianity and purity in finite dimension*, Int. J. Quant. Inf. **7**, 97 (2009).
[2] Marco G. Genoni, Matteo G. A. Paris, Konrad Banaszek, *Quantifying the non Gaussian character of a quantum state by quantum relative entropy*, Phys. Rev. A **78**, R060303 (2008).
[3] Marco G. Genoni, Matteo G. A. Paris, Konrad Banaszek, *A measure of the non-Gaussian character of a quantum state*, Phys. Rev. A **76**, 042327 (2007).

PHASE TRANSITIONS OF BIPARTITE ENTANGLEMENT

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We analyze the statistical properties of the entanglement (purity) of a large bipartite quantum system. By framing the problem in terms of random matrices and a fictitious temperature, we unveil the existence of two phase transitions, characterized by different spectra of the reduced density matrices. One of the two phase transitions occurs at a negative temperature and one at a positive temperature. The phase transition at negative temperature will be paralleled to another one, that is well known in the study of random matrix models and the conformal field theory literature.

CAVITY INDUCED QUANTUM COOPERATIVE BEHAVIORS

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Two kinds of cooperative effects are discussed for two-level atoms (qubits) interacting with an electromagnetic resonator, both of them concerning the Dicke super-radiance. The first is a static, critical phenomenon: the so called *super-radiant phase transition*, occurring when a large number of qubits is coupled to a single cavity mode giving rise to a quantum phase transition for a critical value of the interaction strength. The second is a dynamic phenomenon, producing (among other effects) the generation and/or preservation of entanglement between qubits even in the presence of cavity losses.

NEUTRON OPTICS INVESTIGATION OF THE STABILITY OF GEOMETRIC PHASES

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In quantum mechanics dynamical and geometrical phases can be defined and measured. They are differently sensitive to fluctuations and dissipative forces. Whereas the dynamical phases are sensitive to the strength of the interaction with the environment the geometric phases depend only on the shape of the excursion curve in phase space. The behaviour of the dynamical phase has been investigated by means of neutron interferometry and the geometric phases have been measured with ultra-cold neutrons using spin-echo systems. The results showed that the geometric phase becomes better defined when the system interacts longer with the related environment, i.e. they showed their robustness against disturbances [1]. This may have important consequences for quantum communication networks.

[1] S. Filipp, J. Klepp, Y. Hasegawa, C. Ponka-Spehr, U. Schmidt, P. Geltenbort, H. Rauch, *Experimental Demonstration of the Stability of Berry‘s Phase for Spin-1/2 Particles*, Phys.Rev.Lett. 102 (2009) 030404

PHASE-SPACE DESCRIPTION OF FINITE QUANTUM SYSTEMS

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Phase-space methods offer the advantage of representing quantum mechanics as a statistical theory on phase space. This elegant approach is usually presented in terms of continuous variables, most often position and momentum. However, in spite of the importance of discrete systems in quantum information, their phase-space picture is now so well known. In this talk, I will review the recent advances in this field, stressing geometrical aspects arising in the construction of a proper Wigner function or coherent states for these systems.

FACTORIZATION OF NUMBERS, SCHRÖDINGER CATS AND THE RIEMANN HYPOTHESIS

Wolfgang P. Schleich

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In this talk we connect the three different topics of factorization of numbers, Schrödinger cats and the Riemann hypothesis. The bridge between these areas is the concept of a Gauss sum.

Gauss sums manifest themselves in various phenomena such as the Talbot effect, wave packet dynamics or quantum carpets. Moreover, Gauss sums can be used to efficiently factor numbers. In the meantime five experiments have used such an approach. They rely on NMR techniques, the physics of cold atoms and femtosecond pulses. At the moment the largest number that was factored using a Gauss sum algorithm is a 17 digit number. The talk summarizes these activities.

Moreover, we propose an elementary quantum system which provides us with the Riemann Zeta function. We show that its zeroes are a consequence of the interference of two quantum systems with opposite phases. However, the preparation of such a superposition state (Schrödinger cat) is impossible unless one takes advantage of entangled quantum systems. In this sense analytic continuation familiar from complex analysis finds entanglement as its analogue in quantum mechanics.

QUANTUM THEORY AND REALITY

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Quantum theory is our most successful physical theory. We know how to apply it but we do not know why. The theory does not even tell us which entities it talks about. If I assign a state vector to a system, is this an element of reality? As such it has to be residing in the objects we observe. Some claim that it represents our knowledge only. This opens the question ”Whose knowledge?”
I consider the observations provided by the conventional quantum formalism and, in particular, the clues it reveals about the character of reality. Considering physical Gedanken-experiments, I claim that the state vector must somehow be a genuine attributes of the real world. However, for it to be able to carry its information aspects, we are forced to assert that also the knowledge has to have real presence independent of who the observer happens to be. Such an information concept is in agreement with modern quantum discussions but lacks a role in the standard formulation of physical practice.

THE FFLO STATE FOR ULTRACOLD FERMI GASES IN OPTICAL LATTICES AND THE RESPONSE TO PERTURBATIONS

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We consider density imbalanced ultracold Fermi gases in 1, 2, and 3 dimensional optical lattices. We find the parameter window for non-uniform order parameter FFLO state versus phase separation to be considerably larger than in the free space case, due to the flatness and nesting of the majority and minority component Fermi surfaces in the lattice [1]. The VanHove singularities leave striking signatures to the phase diagrams and the FFLO state is clearly reflected in RF- and photoemission spectroscopy, especially in 1 D [2], making observation of this exotic pairing state feasible. We also discuss the connection of the RF-spectroscopy to the quantum measurement problem [3,4].

Furthermore, we consider the internal Josephson effect in a four-component Fermi mixture, derived using the fully self-consistent approach where final state interactions can be taken into account [5]. We show that asymmetric oscillations, that are unique to ultracold atom systems, can only be explained by dynamics of the Josephson oscillation phenomenon and not by the static picture of simultaneous tunneling of a Cooper pair. Furthermore, we consider a trapped three-component Fermi mixture within the Bogoliubov-deGennes formalism and predict the spatial co-existence of two superfluids [6].

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NOVEL CONCEPTS OF QUANTUM SEARCH IN DATABASES OF TRAPPED IONS

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The quantum search algorithm of Grover [1] has been one of the driving forces behind the rapid expansion of the field of quantum computation. I will review the implementations of Grover's algorithm, with a specific focus on trapped ions. The standard recipes demand the use of a large number of elementary quantum gates, which require a very high fidelity of each single gate for a reliable operation. We have proposed several novel implementations of Grover's algorithm in a linear chain of trapped ions, which use the intrinsic symmetries of the system to realize the Grover operations — the oracle call and the reflection about the mean — in much fewer physical steps than in the standard approaches [2,3,4]. The quantum register comprises all collective states with m ionic excitations, with examples for $m = 1, 2$ and $N/2$. The database is therefore nonclassical for its size scales as N^m; for $m = N/2$ the scaling is exponential vs N. The system is initialized in an even superposition of all register states, i.e. in the symmetric Dicke state with N ions sharing m excitations [5]. The reflection-about-the-mean operator is produced merely by global addressing of the ion string by an off-resonant pulse with a suitable area [6], whereas the oracle operator is a conditional phase gate. This simplification should allow a demonstration of quantum search in databases of hundreds to thousands of elements without needing to synthesize multiple multi-qubit quantum gates.

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TOWARDS HIGHER DIMENSIONS OF HILBERT SPACE

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Multiports provide the possibility of experimentally realizing any unitary operator in any integer dimension Hilbert space. This is done by constructing a web of beam spiltters, in modern language Hadamard transformations, and phase shifters. This opens up the possibility of exploring coherent phenomena in Hilbert spaces of, in principle, arbitrarily high dimension. In the talk I will show how this can be used to implement directly various realizations of Kochen-Specker type experiments. I will also discuss how it then also becomes possible to experimentally investigate the question of the number of mutually unbiased bases in any Hilbert space of discrete dimension. I will discuss both single-photon and entangled-photon experiments in that context.

UNAMBIGUOUS IDENTIFICATION OF COHERENT STATES

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We shall present results on unambiguous identification problems for coherent states of modes of electromagnetic field. In particular, we shall propose simple linear optics implementations of optimal strategies for unambiguous comparison and unambiguous discrimination of unknown coherent states. The optimality of the comparison setup originally proposed in [1] will be proved and extended to the case of multiple copies. In this case, we are given n copies of states $|\alpha\rangle$ and m copies of state $|\beta\rangle$ and the goal is to design a measurement from which either an equality, or a difference of α and β can be unambiguously concluded. In the second task in its simplest form we shall consider a pair of modes described by unknown coherent states $|\alpha\rangle, |\beta\rangle$. However, on top of that an additional mode is given in a coherent state $|\gamma\rangle$ such that either $\gamma = \alpha$, or $\gamma = \beta$. We shall design an experiment in which the identity of γ is unambiguously determined [2]. In fact, the experimental setup is consisting of three beamsplitters and two photodetectors only. It was experimentally implemented by the group in Olomouc [3]. Its extension to identification among n possible coherent states can be seen as a specific quantum database encoding classical information. We shall investigate whether reference states after the measurement can be recovered and further used for subsequent usage. We shall show that in spite of the fact that the recovered reference states are disturbed by measurements they can be repeatedly used for unambiguous identifications [5] with relatively high conditional success probability. We shall also give an analyzis of the role of various imperfections (technical noise) in preparation of the unknown and the reference coherent states on the performance of the unambiguous identification setup.

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Contributed Talks

ATOM-LIGHT ELEMENTARY EXCITATIONS IN A PERIODIC ENSAMBLE OF ULTRACOLD ATOMS

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We study the propagation of light in a periodic system of atoms trapped in the lowest vibrational state of a deep optical lattice. We derive a *complex* energy excitation spectrum of the atom-light field which is valid for any Bravais lattice and takes into account both the vectorial character of the light and the quantum atomic motion. The imaginary part of the excitation spectrum is related to the loss caused by the possible transition of the atoms to an excited vibrational state. The real part shows a gapless spectrum for the main lattice geometries we analyzed. The finite size of the gaussian harmonic oscillator ground state has a non-negligible effect on the excitation spectrum in real systems, and naturally leads to a divergence free spectrum for an infinite system. We analyze the main practical issues related to a realistic realization of the system, and discuss the most favorable atomic species.

CASIMIR FORCES BETWEEN SPHERES IN DIELECTRIC MEDIA

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Using the Lorentz-force method within macroscopic quantum electrodynamics we consider the problem of Casimir forces between spheres, where both the spheres and the background have non-trivial dielectric properties. The general mode decomposition of the Maxwell stress tensor shows clearly how the force depends on an effective geometry that the spheres embody. By interpolating solutions in the relevant perturbative regions (at large and small inter-sphere separations) one is able to obtain a complete solution for all separations. It is possible to make comparisons with both the proximity force approximation (PFA) and also that predicted by the Minkowski stress tensor. These results are then amenable to experimental testing within a colloid physics setting.

TRIPARTITE ENTANGLEMENT TRANSFER FROM (TO) RADIATION MODES TO (FROM) TRAPPED ATOMS IN DISSIPATIVE ENVIRONMENTS

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Multipartite entanglement is a key resource which plays a major role in almost all physical systems of interest for quantum information processing. Recently, the bipartite process of entanglement transfer from a freely propagating quantized light to localized atomic systems has been widely investigated and achieved experimentally. The natural extension of these studies concerns multipartite entanglement, whose structure is currently under investigation, especially in the case of mixed states. Indeed quantum correlations in multipartite systems have a much richer structure than in the bipartite case and may be used to implement improved information protocols and distributed quantum computing, as well as to reveal higher-nonlocality features of quantum mechanics. In particular, tripartite entanglement is a resource to increase the security of quantum cryptography and it finds applications in quantum secret sharing and quantum cloning. Here we address cavity QED for quantum interfaces and investigate the issue of tripartite entanglement transfer from flying radiation modes to localized qubits or viceversa.

We have developed a Monte Carlo wave function method to study the interaction between three-mode quantized radiation and three two-level atoms located in separated resonators, each one resonantly coupled to a cavity mode, where both cavity dissipation and atomic spontaneous emission are taken into account. Firstly we describe a process where each of the three modes of an entangled radiation is injected into a cavity, containing an atom. We assume that the atoms are prepared in a separable state and the radiation in different entangled states, such as qubit-like generalized Schmidt decomposition states or continuous-variables states. By a full open system dynamics treatment we generalize a recent work [1] and derive the conditions for optimal transfer of entanglement, evaluated by the tripartite negativity [2], also describing the entanglement dynamics and the mapping of radiation onto qubit states.

Then we investigate the entanglement transfer from three atoms prepared in states such as Greenberger-Horne-Zeilinger or W states, to three-mode separable radiation fields resonantly coupled to the cavities. We show that it is possible to generate entangled states of the radiation leaving the cavities, also in the presence of incoherent cavity and atomic decay rates. In turn this represents a novel scheme to produce entangled radiation, alternative to standard techniques of linear and nonlinear optics. Though entanglement can be quantified only for vacuum incident radiation, its existence can be proven for general CV field states [3].

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ON THE INFLUENCE OF RESONANCE PHOTON SCATTERING ON ATOM INTERFERENCE

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Atom interferometry uses the solutions of the time-dependent Schrödinger equation for particles interacting with gratings of various types [1]. These characteristics make modern theories of quantum interference essentially different from earlier theories. We express such solutions in a form in which the probability amplitude of particle transverse momenta is very essential [2]. This form encompasses near and far field and describes all features of particle diffraction and interference in a unified way [3]. In particular, it is very useful to explain [4] the experiment carried out by Chapman et al. [5] in which single photons were scattered off atoms which passed through the first grating of a three-grating Mach-Zehnder interferometer. By measuring the transmission of atoms through the third grating, the influence of the photon scattering processes on the atom interference was investigated. Authors found revivals of contrast for $d_p/\lambda > 0.5$, where d_p is the distance between atomic paths at the scattering locus and λ_i the scattered photon wavelength. This result induced to a controversial discussion [6,7,8], in particular about the question: Is complementarity more fundamental than the uncertainty principle? In our explanation, wave and particle properties are compatible, since both are present and play a role. An analytic expression for the dependence of the contrast on the ratio d_p/λ was derived for all values of this ratio. This theoretical result is in fairly good agreement with the measured contrast. The distribution of transferred momenta during photon scattering causes the decrease of the contrast as the ratio d_p/λ approaches 0.5 and several subsequent revivals having decreasing maxima. There is no loss of coherence of the single atom wave function. Our approach essentially differs from the approaches based on the principle of complementarity, since they predict a loss of contrast at $d_p/\lambda \cong 0.5$ and face the problem of explaining the presence of revivals.

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X-ENTANGLEMENT OF PDC PHOTON PAIRS

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Mastering the techniques involving sources of entangled photon pairs has become vital for the implementations of many quantum networks and quantum computing schemes. So far, parametric down-conversion (PDC) demonstrated the most efficient room-temperature source of entangled photon pairs, employed in successful implementation of quantum communication schemes. At the very heart of such technologies lies the quantum interference between photonic wave functions, which depends crucially on the spatio-temporal mode structure of the photons.
In this work, this issue is addressed from a peculiar and novel point of view, that is, the non factorability in space and time of the PDC bi-photon entanglement. The idea is driven by recent investigations in nonlinear optics [1] that outlined how in nonlinear media the angular dispersion relations impose a hyperbolic geometry involving temporal and spatial degrees of freedom in a non-factorable way. The wave object that captures such a geometry is the so-called X-wave (the X being formed by the asymptotes of the hyperbola).
Here we turn our attention to the genuine quantum properties of PDC, and we demonstrate the hyperbolic geometry underlying the spatio-temporal structure of the PDC entanglement and its non-factorability with respect to space and time [2]. As for the X-waves encountered in nonlinear optics, the X-shape of the bi-photon correlation is imposed by the phase-matching mechanism governing the PDC process, and following this analogy we coined the name of *X-entanglement*. This represents a entirely new concept, because investigations on the quantum state of of PDC have been performed to date mostly in a purely either temporal or spatial framework. Our approach, which takes into account the nonfactorability of the state in space and time, leads to relevant elements of novelty, namely **i)** the possibility of tailoring the temporal bandwidth of the bi-photons by manipulating their spatial degrees of freedom, or viceversa and **ii)** the extreme relative localization of the X-entanglement in time and space, with bi-photon correlation times and lengths in the femtosecond and micrometer range, respectively. It should be stressed that both the non-factorability and the extreme localization are not present in the detection schemes used so far, which usually select small angular portions of the PDC fluorescence. In the metrology domain, our researches have high potentialities for e.g. ultra-precise measurements of time delays and clock synchronizations, due to the ultra-short localization in time of the entangled photons.

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DYNAMICS OF QUBITS COUPLED TO A NONLINEAR DISSIPATIVE SYSTEM

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Dynamics of a pair of qubits interacting with the quantized Duffing oscillator is studied. It is shown that the oscillator part of the qubits-oscillator system in the semi-classical limit is well described by the classical model despite the oscillator-qubit interaction. On the other hand, exact quantum dynamics of the qubits pair is quite different from the classical model as long as there is non-negligible qubit-oscillator interaction. It is also concluded that the decoherence of the qubits pair by the dissipative nonlinear oscillator is more effective when the oscillator is in the more classical regime, and if the semi-classical oscillator dynamics is chaotic rather then regular.

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QUANTUM STATE PREPARATION IN MICROTRAPS

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Reaching high fidelities while not compromising fast time scales is one of the most important criteria that ultimately any realistic quantum information processor must fulfill. This usually requires excellent time-dependent control over several experimental parameters, making it technically challenging. For not-completely time-critical applications, however, alternative adiabatic techniques can be used that allow to transfer time-dependent control into fixed system parameters.

Here we investigate techniques for state preparation of single atoms in systems of spatially separated micro-traps. For such systems it was recently shown that an analogue to the celebrated three-level STIRAP technique in optics can be constructed, allowing for high fidelity atomic transport as well as EIT and CPT [1]. As spatial atom-optical systems contain various additional degrees of freedom as compared to optical systems (e.g. multiple spatial dimensions, particle interactions, quantum statistics, etc.), they hold a large promise for developing new and exciting techniques based on dark states.

As an example we consider a four trap diamond arrangement in two dimensions and show that an atom trapped initially in a single trap can be transferred into an arbitrary, but well defined, spatial superposition state. This process requires only control over individual trapping frequencies and the ability to carry out a STIRAP type positioning sequence of the traps. We will show that this process does not only allow for large fidelities when carried out perfectly, but is also robust against many experimental uncertainties.

Finally we will discuss how such systems can be created using rf-potentials or atomic waveguides on atom chips.

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FUNDAMENTAL MECHANISMS OF NOISE-SUPPORTED QUANTUM DYNAMICS AND ENERGY TRANSFER IN BIOLOGICAL SYSTEMS

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Transport of excitations through networked systems plays an important role in many areas of physics, chemistry, and biology. The uncontrollable interaction of the transmission network with a noisy environment is usually assumed to deteriorate its transport capacity, especially so when the system is fundamentally quantum mechanical. Here we identify key mechanisms through which dephasing noise, contrary to expectation, may actually aid transport through a dissipative network. These are processes that lead to the suppression of destructive interference and exploitation of line broadening. We illustrate how these mechanisms operate using simple examples and show that their overall effect is the opening of additional pathways for excitation transfer. We investigate numerically and analytically noisy transport dynamics on a fully connected network and study numerically the Fenna-Matthew-Olson (FMO) complex, the former to elucidate the fundamental principles, and the latter to show how these principles can explain the remarkable efficiency and robustness of excitation energy transfer from the light-harvesting chlorosomes to the bacterial reaction center. These results strongly suggest that Nature actively utilizes the fundamental sensitivity of quantum systems to noise and that the way Nature seems to exploit environmental noise is intrinsically robust to changes in the properties of the dissipative quantum network. This robustness corroborates the idea that the principles we describe are of relevance in a wide variety of physical and biological transport networks, and furthermore, that they could be exploited for achieving robust and efficient energy transfer in artificial structures.

TELEPORTATION OF ENTANGLED TWO-MODE CONTINUOUS VARIABLES

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We will consider teleportation of entangled two-mode state of continuous variables. At present, quantum teleportation of single photon states and continuous variables have been well studied studied both theoretically and experimentally. Protocols were proposed for teleporting a two-qubit entangled state [1] and an entangled continuous variable (CV) state [2]. In order to teleport an entangled two-mode CV state it is necessary to have four-mode field in an entangled state. For this purpose, application of two optical parametric amplifiers are considered in [2]. We showed in [3] that entangled four-mode state for continuous variables can be obtained in coupled optical parametric processes proceeding in a single aperiodical nonlinear photonic crystal (APNC).

In this paper we present the results of our further studying generation of the entangled four-mode CV state in coupled nonlinear optical processes and their application for teleportation of an unknown entangled two-mode CV state.

We analyze generation of optical four-mode field with frequencies $\omega_1, \omega_2, \omega_3$ and ω_4 and with various "inner" structure of two-mode entanglement in APNC. It is attained by using of pumping waves with multiple frequencies. So, one can realized CV entanglement between frequencies ω_1 and ω_2, and ones ω_3 and ω_4 in the single one-frequency field[4]. In the field of two-frequency pump the CV entanglement between the following frequencies can be implemented: ω_1 with ω_2 and ω_4, and also ω_2 with ω_1 and ω_3. Finally, if the pump is three-frequency one, then the CV entanglement between the frequencies ω_3 and ω_4 occurs. For various ways of obtaining the entangled four-frequency CV state we calculated a fidelity for teleportation of two-frequency entangled CV state. It is established that in some cases the teleportation can be almost perfect.

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DYNAMICAL SYMMETRY REDUCTION AND DISCRETE TOMOGRAPHY OF A Ξ ATOM

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When implemented using a reasonable Hamiltonian, the tomography of a three–level Ξ atom is complicated by the equidistant energy levels of the atom. This restricts the possible transformations to those in the SO(3) subgroup of SU(3). Although complete reconstruction is possible for a single Ξ atom using a continuous set of tomograms, the discrete optimal set of tomograms, related to MUBs in dimension 3, are not accessible by time evolution. We discuss here the search for an optimal set of discrete basis states compatible with the reduced SO(3) symmetry of the system.

BROKEN SYMMETRY AND QUANTUM TO CLASSICAL TRANSITION IN SYSTEM OF FINITE SIZE WITH A SPONTANEOUSLY BROKEN SYMMETRY: A MEAN FIELD APPROACH

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A spontaneously broken symmetry implies the existence of different ground states connected with each other by symmetry transformations. It is known that the thermodynamic limit, because of the "superselection rules", interference between macroscopic states cannot exist. We studied the disappearence of state interference and entanglement as the macroscopic limit is approached for models belonging to different classes of symmetry: the Ising and anysotropic XY model in the presence of a factorizing transverse field, belonging to a discrete symmetry case, and the BCS and Heisenberg spin model ,where the symmetry is continuous. The approach to the thermodynamic limit is studied by means of the exact solution in the case of the factorized XY chain and the Heisenberg model, while a mean field theory is introduced as far as the Ising and the BCS models are considered. The transition from quantum to classical behaviour is found to occur exponentially or algebraically with the increasing of the size system N respectively in the case of a discrete or continuous symmetry breaking.

HIERARCHIES OF GEOMETRIC ENTANGLEMENT AND APPLICATION IN QUANTUM SPIN CHAINS

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We introduce a class of generalized geometric measures of entanglement. For pure quantum states of N elementary subsystems, they are defined as the distances from the sets of K-separable states ($K = 2, \dots, N$). The entire set of generalized geometric measures provides a quantification and hierarchical ordering of the different bipartite and multipartite components of the global geometric entanglement, and allows to discriminate among the different contributions. The extended measures are applied to the study of entanglement in different classes of N-qubit pure states. These classes include W and GHZ states, and their symmetric superpositions; symmetric multi-magnon states; cluster states; and, finally, asymmetric generalized W-like superposition states. We discuss in detail a general method for the explicit evaluation of the multipartite components of geometric entanglement, and we show that the entire set of geometric measures establishes an ordering among the different types of bipartite and multipartite entanglement. In particular, it determines a consistent hierarchy between GHZ and W states, clarifying the original result of Wei and Goldbart that W states possess a larger global entanglement than GHZ states. Furthermore, we show that all multipartite components of geometric entanglement in symmetric states obey a property of self-similarity and scale invariance with the total number of qubits and the number of qubits per party.
As a relevant application of the hierarchical geometric measure, we quantify multipartite entanglement in quantum spin chains by computing several components of the geometric measures associated with specific K-separable N-qubit states. In particular, we study the ground state of the exactly solvable (1-dimensional) XY model. This analysis is interesting both for the connection between multipartite entanglement and quantum phase transitions, and for a possible efficient implementation of quantum information and communication protocols in many-body systems.

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PHOTON DISTRIBUTION IN THE DYNAMICAL CASIMIR EFFECT WITH AN ACCOUNT OF DISSIPATION

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A theory of quantum damped oscillator with an arbitrary time dependence of the frequency and damping coefficient [1,2], based on the Heisenberg–Langevin equations with delta-correlated stochastic force operators, is applied for studying the dynamical Casimir effect in a cavity with a periodically photo-excited semiconductor boundary. New analytical results, concerning the mean number of created photons $\langle N \rangle$, its variance $\sigma_N = \langle N^2 \rangle - \langle N \rangle^2$, and the photon distribution function $f(m) \equiv \langle m|\hat{\rho}|m \rangle$, are given. It is shown that under resonance conditions, the field mode goes to the so called superchaotic quantum state with $\sigma_N = 2\langle N \rangle^2$. A simple asymptotical formula

$$f_{as}(m) = [2\pi \langle N \rangle (m + 1/2)]^{-1/2} \exp[-(m + 1/2)/(2\langle N \rangle)]$$

for highly excited mixed Gaussian states is obtained. It does not depend on concrete values of damping coefficients and correlation coefficients of the noise operators. But damping plays an important role, because in its absence the quantum purity is preserved, and the distribution function has well known oscillations, whereas the function $f_{as}(m)$ shows a smooth behavior. The dependence of mean number of photons $\langle N \rangle$ on different parameters, especially on damping and diffusion coefficients, is studied.

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LINEAR-OPTICAL QUANTUM INFORMATION PROCESSING – A FEW EXPERIMENTS

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Quantum information processing requires precise manipulation and measurement of the states of quantum systems. Even if linear-optical implementations of quantum operations are mostly probabilistic, they have a big potential for practical realization of many quantum information processing tasks. In this contribution we review some our recent experiments in this field. Namely, an Encoder of two qubits into a single qutrit [1], Optimal symmetric and asymmetric phase-covariant quantum cloning machines [2-5], a Programmable discriminator of weak coherent states [6], Partial-SWAP gates including entangling square-root of SWAP [7], Partial symmetrization and anti-symmetrization of two-qubit states [8], and a Programmable gate for an arbitrary rotation of a single qubit along the z axis [9]. Some of these experiments were built from bulk optical elements and the information was encoded into polarization states of photons. The others were based on fiber optics. In these cases the information was encoded into spatial modes, i.e. each photon could propagate through two or more optical fibers.

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SPECTRAL ENTANGLEMENT OF SPDC BIPHOTON STATES

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We analyze theoretically spectra and degree of entanglement of biphoton states produced via Spontaneous Parametric Down-Conversion (SPDC) with the type-I collinear degenerate phase matching and a pulsed pump. The degree of entanglement is characterized by the experimentally measurable parameter R defined as the ratio of the single to coincidence spectral widths [1]. Though the biphoton spectral wave function is not similar to the double-Gaussian one, the parameter R is found analytically in the domains of short and long pump pulses and is interpolated to the region of intermediate pulse durations [2]. The degree of entanglement is found to be very high in all ranges of pump-pulse duration τ, short, long and intermediate. Even in the minimum, occurring around $\tau \sim 1\,\mathrm{ps}$, $R \approx 73 \gg 1$. The parameter $R(\tau)$ is compared with the numerically calculated Schmidt number $K(\tau)$ [3], and these two functions are found to be very close to each other, which opens a way for a direct experimental measurement of the degree of spectral entanglement. We found analytically the reduced density matrix associated with the spectral wave function, its eigenfunctions (Schmidt modes) and eigenvalues in both regions of short and long pump pulses. Two-time temporal distribution of the signal and idler photons is also analyzed [2].

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NON MARKOVIAN DYNAMICS OF A SINGLE ELECTRON SPIN COUPLED TO A NUCLEAR SPIN BATH BY NON-UNIFORM HYPERFINE INTERACTION: THE ROLE OF THE EFFECTIVE COUPLING CONSTANT

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The dynamics of single spin embedded in solid matrices, has gained more and more interest in the last decades both from theoretical and applicative point of view. Exploiting the time-convolutionless (TCL) projection operator technique we analyze the time evolution of a single localized electron spin coupled to a nuclear spin bath via non-uniform hyperfine interaction. The coherence and the populations of the central spin are determined analytically and compared with the exact ones obtained through numerical simulation. Our results demonstrate that the TCL approach gives an excellent approximation for the description of short-time dynamics as well as long time behavior in the strong field regime. The key point is the introduction of an effective coupling constant that allow us, at least on short time-scale, to describe the complex reduced dynamics in terms of the exactly analytically solvable model of a single electron spin coupled uniformly with a nuclear bath.

FAILURE OF THE ROTATING-WAVE APPROXIMATION IN THE DESCRIPTION OF THE EVOLUTION OF ENTANGLEMENT

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The basis states for entanglement in a two-qubit system are four mutually orthogonal Bell states. The states can be divided into two grups, one involving linear superpositions of the spin correlated states and the other involving spin anti-correlated states [1]. The states belonging to these groups are often called two-photon and one-photon entangled states, respectively. It is well established that an entanglement encoded in the Bell states of a two-qubit system with correlated spins exhibits completely different evolution properties than that encoded in states with the anti-correlated spins [2]. A complete and abrupt loss of the entanglement, called the entanglement sudden death, can be found to occur for the spin correlated states, but the entanglement evolves without any discontinuity or decays asymptotically for the spin anti-correlated states. The same behavior has been predicted for two qubits mutually interacting through the coupling to a common environment [3]. However, all of these analysis were restricted to the rotating-wave approximation (RWA) made on the interaction Hamiltonian.

Here, we raise the question of the validity of the RWA approximation in the description of the evolution of entanglement encoded in the spin anti-correlated states. By way of an example of two identical qubits strongly coupled to a single-mode cavity field, we show that under the non-RWA Hamiltonian the time evolution of an initial entanglement encoded in the spin anti-correlated states may undergo significant quantitative deviations from that predicted under the RWA. The results show that the entanglement may undergo a discontinuity, the sudden death phenomenon. We show that the better the RWA is in describing the dynamics, the weaker the entanglement sudden death behavior, and only in the limit of a weak coupling, the RWA is an excellent approximation for the entanglement evolution of the spin anti-correlated states. However, the sudden death requires either an initial or a transient buildup of the population in the upper two-photon state of the system. One could argue that this rules out the discontinuity in the entanglement evolution since only a single excitation was present initially. We shall demonstrate that this is not the case if one considers an evolution with the non-RWA Hamiltonian and interpret this result as a consequence of the principle of complementarity between the evolution time and energy and the presence of the counter-rotating terms in the interaction Hamiltonian.

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QUANTUM INTERFACE TO HARDLY CONTROLLABLE NOISY SYSTEM

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A transmission of quantum state from well-controllable source to hardly controllable noisy target by a quantum interface is a recent problem in modern quantum physics. For the continuous-variable interface, the source and target systems are described as quantum linear harmonic oscillators. A fundamental rule of preservation of commutation relations for any quantum evolution introduces quantum noise penalty in any unitary interface with a finite conversion efficiency. In practice, this noise penalty is also higher than just vacuum noise, caused by the own noise of the target. This fundamental quantum noise penalty cannot be simply compensated just by the pre-amplification used in the classical physics for this purpose. Since any quantum pre-amplification process will be also accompanied by vacuum noise penalty, it adds even more noise into the interface. Practically, not many interfaces are available for the same target, therefore, all the operations with the target are typically through this single interface. This makes a problem how to achieve a high-fidelity transfer of unknown quantum state through the interface very demanding. A low conversion efficiency of the coupling reduces fundamentally the fidelity of converted quantum states. In addition, the target typically exhibits a high background noise, for example, if it is matter system at a room temperature. If the efficiency is low and background target noise is quite high, quantum properties of the interface completely vanish.

We propose novel method how to approach ideal continuous-variable quantum interface converting unknown quantum state to an arbitrarily noisy target through an arbitrarily weak coupling from the realistic interface described above. For the linear interface, the method is based on the quantum pre-amplification and continuous-variable feed-forward control. Applying this method, unknown state of source is perfectly transferred to the noisy target for any coupling strength. On the hardly controllable target, only the displacement operation has to be implemented, which is available through the same interface. Interestingly, only finite gain of the pre-amplification is required. To transfer the unknown state through the inverse interface, from the hardly controllable system back to more controllable system, the pre-amplification is substituted by the post-amplification. Further, instead the feed-forward scheme, the continuous-variable entanglement is used to avoid typically inefficient detection of the target system. In this case, ideal inverse interface can be only approached if the quantum correlations in suitable resource entangled state connecting the interface and amplifier are intensive. Finally, it is proved that both these techniques can be generalized for any interface transferring the quadrature variables of the continuous-variable system from the source to the target without their mutual cross-talk.

LINEAR OPTICAL FREDKIN GATE BASED ON PARTIAL-SWAP GATE

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We present a novel dedicated scheme for linear optical quantum Fredkin gate [1] based on the combination of recently experimentally demonstrated linear optical partial-SWAP gate [2] and controlled-Z gates [3]. Both heralded gate and simplified post-selected gate operating in the coincidence basis are designed. The suggested setups have a very simple structure. They involve less optical elements than previously proposed schemes [4,5] and require stabilization of only a single Mach-Zehnder interferometer. A proof-of-principle experimental demonstration of the post-selected Fredkin gate appears to be feasible and within the reach of current technology.

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GROUND STATE FACTORIZATION AND QUANTUM PHASE TRANSITION IN DIMERIZED SPIN CHAINS

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The emergence of ground state factorization in dimerized XY spin chains in a transverse field is discussed [1]. Together with the usual ferromagnetic and antiferromagnetic regimes, predicted since long time [2], a third case emerges, consisting of an antiferromagnetic Neél-type ground state where pairs of spins represent the unitary cell. As in the regular XY model, the factorizing field represents a border line between region exhibiting different symmetry-breaking mechanisms, the same separation appears also in the dimerized chain. This result is achieved by performing the diagonalization of the Hamiltonian for finite-size chains, and then by realizing the thermodynamic limit. Furthermore, the factorizing field, when it exists, represents an accidental degeneracy point of the Hamiltonian. Finally, by generalizing the work of Giampaolo *et al.* [3], we extend the study of the existence of ground state factorization to a more general class of models.

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DIVISIBILITY OF GAUSSIAN QUANTUM CHANNELS

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Gaussian quantum channels play an important role in quantum optics. In particular, they can be effectively used to model transmission of light through optical fibers.

We investigate the possibility of dividing quantum channels into concatenations of other channels. The focus is on Gaussian quantum channels. In mathematical terms, we hence study the semigroup structure of the set of Gaussian quantum channels.

We show that every Gaussian quantum channel can be divided into two other Gaussian channels. Therefore, there are no 'indivisible' Gaussian channels. Interesting differences appear when some finer divisibility properties are studied. Especially, not all Gaussian channels can be divided into infinitesimal parts.

DISCRIMINATION OF MIXED STATES WITH MAXIMUM CONFIDENCE AND MINIMUM PROBABILITY OF INCONCLUSIVE RESULTS

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Quantum state discrimination lies at the heart of quantum communication and quantum cryptography. The task is to determine the state of a quantum system which is prepared in a certain state, belonging to a finite set of given states. When the states are non-orthogonal, they cannot be distinguished perfectly, and therefore discrimination strategies have been developed which are optimized with respect to various criteria.

In unambiguous discrimination errors are not allowed, at the expense of admitting inconclusive results, the probability of which is minimized in the optimum measurement. When the states in the given set are pure, they must be linearly independent, and when they are mixed, the supports of their density operators must be different in order to enable unambiguous discrimination. For the case that some or all states in the set cannot be unambiguously discriminated, recently the strategy of discriminating them with maximum confidence has been introduced [1].

Here we focus on the discrimination of two mixed states. We investigate the optimized measurement that distinguishes between them with maximum confidence for each of the two distinct outcomes, thereby keeping the probability of inconclusive results as small as possible. In the special case that both states have non-vanishing kernels, the measurement is equivalent to optimum unambiguous discrimination. Our treatment generalizes previous results derived for the optimum unambiguous discrimination of two mixed states [2]. Provided that the rank of the detection operators associated with the two conclusive outcomes does not exceed unity, we obtain a general solution for the optimum measurement, valid for arbitrary prior probabilities of the states [3].

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DICKE MODEL AND ENVIRONMENT-INDUCED ENTANGLEMENT IN ION-CAVITY QED

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We investigate the realistic experimental conditions under which the Dicke model [1] can be implemented in the ion-cavity QED context. It has been previously shown that collective subradiant and superradiant modes predicted by the Dicke model exist even in the presence of cavity losses [2]. Now we take also the inevitable atomic spontaneous emissions into account, and show how ideal subradiance and superradiance can still be observed. As an application, we propose an experiment to generate entanglement between two ions by exploiting the existence of the subradiant state. We investigate the conditions to achieve optimal entanglement generation and we show that they are achievable with current experiments [3,4].

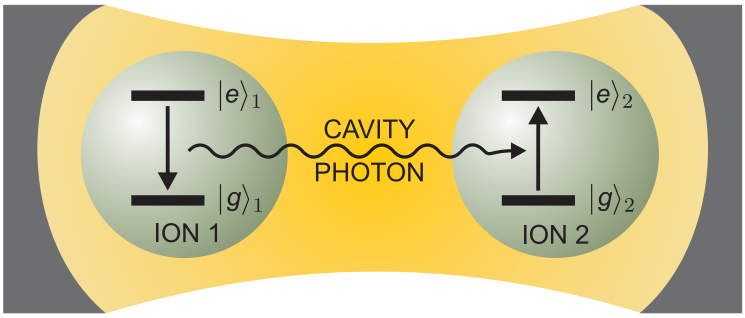

Figure 1: Two binary quantum objects interacting through a quantized electromagnetic mode supported by a cavity resonator. Dynamics is described by the Dicke model.

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CONTINUOUS VARIABLE ENTANGLEMENT IN OPEN QUANTUM DYNAMICS

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In the framework of the theory of open systems based on completely positive quantum dynamical semigroups [1,2], we study the continuous variable entanglement for a system consisting of two independent harmonic oscillators interacting with a general environment. We solve the Markovian master equation for the time evolution of the considered system and, by using Peres–Simon necessary and sufficient criterion for separability of two-mode Gaussian states [3,4], we describe the generation and evolution of entanglement in terms of the covariance matrix, for an arbitrary Gaussian initial state. We show that for certain values of diffusion and dissipation coefficients describing the environment, the state keeps for all times its initial type: separable or entangled. In other cases, entanglement generation, entanglement sudden death or a periodic collapse and revival of entanglement take place [5]. In particular, we describe the dynamics of entanglement in terms of the squeezing coefficient of the initial Gaussian state and the temperature of thermal bath. We analyze also the time evolution of the logarithmic negativity, which characterizes the degree of entanglement of the quantum state [6].

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DYNAMICS OF A MANY-PARTICLE LANDAU-ZENER MODEL: FORWARD AND BACKWARD SWEEPS

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We consider nonlinear dynamics of an interacting many-particle system with a slowly changing parameter: a time-dependent Dicke model, which represents a many-body generalization of the Landau-Zener model [1]. Adiabaticity is destroyed when a parameter crosses a critical value, even at very slow sweeping rates of a parameter. We apply semiclassical analysis based on Truncated Wigner Approximation (TWA) and concepts of classical adiabatic invariants. Formulas are derived that accurately describe particle distributions in the Hilbert space at wide range of parameters of the system. The main idea is mapping the system to a Painlevé equation [2-3], a method which has never been used in previous studies [4-9]. We discuss application of our results [9,12,13] to studies of *dynamics of quantum phase transitions* [10,11].

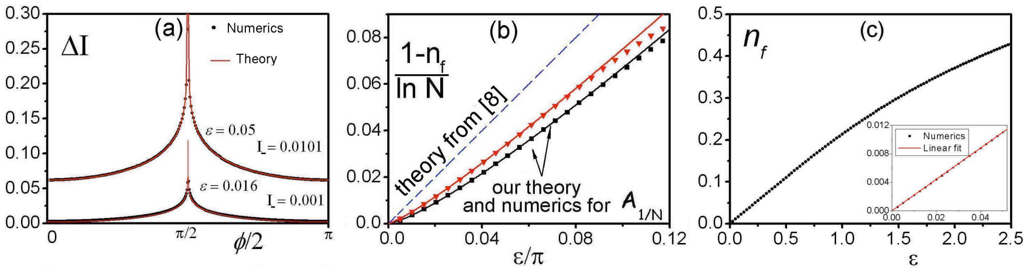

Figure 1: (a) Changes in classical actions for an ensemble of trajectories in a "forward" sweep: theory and numerics [12] (b) number of created bosons in a "forward" sweep (c) number of remaining bosons in a "backward" sweep [13]. Inset shows a linear power-law for small ϵ, with $n_f/\epsilon = 0.220631$, which coincides with the theoretical prediction $\frac{\ln 2}{\pi}$ [13].

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WHEN IS WEGNER'S FLOW GEODESIC?

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Wegner's method of flow equations [1,2] offers a powerful tool for diagonalizing a given Hamiltonian and is widely used in various branches of quantum physics. Here, generalizing this method, we find a moderate condition under which the corresponding flow of a quantum state becomes geodesic in a submanifold of the projective Hilbert space [3]. This implies the geometric optimality of the present method as an algorithm of generating stationary states in quantum state engineering [4]. We illustrate the result by analyzing some physical systems.

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ABOUT POSITION DIFFUSION IN QUANTUM BROWNIAN MOTION

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In classical Brownian motion, a random walk like trajectory can be assigned to the particle of interest. The free particle evolution is interrupted by random momentum “jumps" due to collisions with surrounding gas particles, a process which leads to momentum diffusion. There is no intrinsic position diffusion present (although the position does diffuse in the long term due to momentum uncertainty).

In collisional quantum Brownian motion (CQBM), various authors [1-3] find additional position diffusion and it is argued that any master equation describing quantum friction must include position diffusion in order be completely positive. This observation is somewhat counter intuitive as it corresponds to random position jumps, which are not even possible in classical dynamics.

We first refine the approach of Barnett and Cresser [4], and identify appropriate Kraus operators for a single collision undergone by the Brownian particle from an exact solution of the Schrödinger equation for a gas particle and the Brownian particle interacting via a hard-core potential. A Markovian master equation is then constructed, this step involves introducing a coarse grained time scale large compared to the collision time (as do [1-3]). We show that it is this approximative procedure which results in a master equation which gives the illusion of position diffusion taking place. A more detailed solution on a finer time scale (which would almost certainly result in a non-Markovian master equation) would therefore not be expected to contain such a term, as can be seen to be the case in the work of Hu et al [5].

We test our master equation by calculating equations of motion of the expectation values of the two lowest order moments of position and momentum. We recover the full set of classical equations. If the Brownian particle's velocity is comparable (or even large as in a cloud chamber) to the thermal velocity of the gas particles, this includes non-linear friction.

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QUANTUM MEMORY FOR SURFACE POLARITONS IN METAMATERIALS

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Unlike conventional materials, negative index meta-materials (NIMM) support both electric and magnetic surface polariton (SP) modes that are spatially confined to the media interface with highly reduced losses. We study electromagnetically induced transparency (EIT) based quantum control of SP modes in metamaterial structure. Utilizing SP confinement, we demonstrate the possibility of low loss surface polariton fields with very slow group velocity at EIT conditions. We discuss potential applications in quantum information and quantum memory of weak light fields[1].

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COLLAPSE AND REVIVALS OF THE PHOTON FIELD IN A LANDAU-ZENER PROCESS

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The Landau-Zener process is almost as old as the study of quantum mechanics; it and its generalisations have formed the basis for much of the understanding of state evolution under time-dependent Hamiltonians. I will discuss a generalisation of the Landau-Zener process to a two-level system coupled to a bosonic (i.e. photon) field, initially in a coherent state, applicable to cavity quantum electrodynamics experiments. I will describe how interference effects lead to a dramatic collapse and revival of the photon field amplitude at slow time variation, so slow that the single particle Landau-Zener process would be far in the adiabatic regime[1]. As well as this dramatic collapse and revival, the effects of photon decay in this problem are revealing, demonstrating how applying a time-dependent field may lead to enhanced effects of decay, yet finding that the predicted effects should be accessible in circuit quantum electrodynamics experiments.

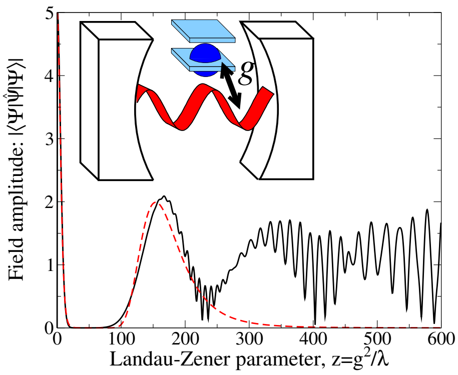

Figure 1: Main figure: Photon field amplitude (y axis) as a function of the rate of driving a two-level system through a Landau-Zener transition. The black solid line indicates the numerical results, showing collapse and revival as a function of driving rate; red dashed line shows a simplified expression.

If there is sufficient time, I will contrast the results of this bosonic system to another generalisation of the Landau-Zener problem, this time considering tunnelling between a localised fermionic level and a continuum of fermionic levels[2]. In this case, interference causes the final many body state to be "clean", containing no particle-hole pairs excitations in the continuum, again demonstrating how interference effects are important.

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OPTIMIZED QUANTUM RANDOM-WALK SEARCH ALGORITHMS

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Shenvi, Kempe and Whaley's quantum random-walk search (SKW) algorithm [Phys. Rev. A 67, 052307 (2003)] is known to require $O(\sqrt{N})$ number of oracle queries to find the marked element, where N is the size of the search space. The overall time complexity of the SKW algorithm differs from the best achievable on a quantum computer only by a constant factor. We present improvements [1] to the SKW algorithm which yield significant increase in success probability, and an improvement on query complexity such that the theoretical limit of a search algorithm succeeding with probability close to one is reached. We point out which improvement can be applied if there is more than one marked element to find.

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TUNNELING TIMES AND COVARIANT MEASUREMENTS

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We consider [1] the time delay of massive, non-relativistic, one-dimensional particles due to a tunneling potential. In this setting the well-known Hartman effect [2] asserts that often the sub-ensemble of particles going through the tunnel seems to cross the tunnel region instantaneously. An obstacle to the utilization of this effect for getting faster signals is the exponential damping by the tunnel, so there seems to a trade-off between speedup and intensity. We prove that this trade-off is never in favor of faster signals: the probability for a signal to reach its destination before some deadline is always reduced by the tunnel, for arbitrary incoming states, arbitrary positive and compactly supported tunnel potentials, and arbitrary detectors. More specifically, we show this for several different ways to define “the same incoming state” and ”the same detector” when comparing the settings with and without tunnel potential. The arrival time measurements are expressed by time-covariant POVMs, but we also consider detection by means of localization measurement performed at a fixed preset time.

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GENERALIZED WIGNER FUNCTION FOR QUANTUM SYSTEMS WITH SU(2) DYNAMICAL SYMMETRY GROUP

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We introduce an alternative Wigner-like quasidistribution function to describe quantum systems with SU(2) dynamic symmetry group [1]. The principal difference with the standard Stratonovich mapping consists in taking into account simultaneously all the irreducible representations of the SU(2) group over which the initial state of a quantum system is expanded. Our Wigner function is defined in a three dimensional group manifold and allows us to "draw" non-diagonal (between irreducible subspaces) elements of the density matrix. An explicit differential Moyal-like form of the star-product is found and analyzed in the semiclassical limit, which opens a possibility to study semiclassical dynamics of quantum systems including "diffusion" among different SU(2) irreducible subspaces. Such diffusion appears only when the system's Hamiltonian mixes irreducible subspaces. Several typical Hamiltonians, which can not be studied in the frame of the standard Stratonovich-Weyl approach, are analyzed in the semiclassical limit.

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FIBER-OPTICAL ANALOGUE OF THE EVENT HORIZON

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The geometry of black holes can be viewed as if space were a medium moving towards their singularities. Where the flow is superluminal such that nothing can escape, horizons are formed. Laboratory analogues of black holes are based on this picture the black hole resembles a river – a moving medium – flowing towards a waterfall, the singularity. Waves on the river propagating upstream at speed c' play the role of light where c' represents c, the speed of light. Suppose as the river approaches the waterfall the flow speed exceeds c'. Clearly, beyond this no wave can propagate upstream. This point of no return is the horizon. According to quantum physics, the black hole emits waves in thermal equilibrium. The waves consist of correlated pairs of quanta. If the medium could be moved at the velocity of light, this radiation could be observed as photons in a laboratory analogue. Our experiment is based on nonlinear optics of pulses in fibers. A

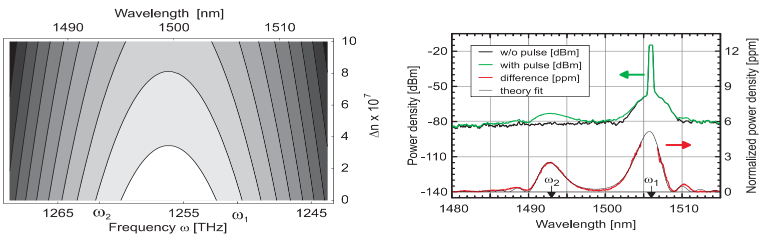

Figure 1: Left: Doppler contours. Right: Measurement of blue shifting at a white-hole horizon. Black curve: just probe, no soliton; green curve: result of the interaction; red curve: difference (lin. scale).[1]

soliton pulse is propagating down an optical fiber and creates a Kerr-induced refractive index modification Δn that moves with the pulse and forms a medium, naturally moving at the speed of light. Consider also a continuous wave of light, a probe, that follows the pulse with slightly higher group velocity. On approach, the Kerr effect slows the probe until the probe's group velocity reaches the pulse's speed. The trailing end of the pulse is a white-hole horizon, an object that light cannot enter unless it tunnels through the pulse. At the horizon of an astrophysical black hole light freezes, reaching wavelengths shorter than the Planck scale. In our case, the probe modes compress, increasing their frequency and blue-shifting. In normal dispersion, the probe slows down until the horizon condition is no longer satisfied. Figure shows the difference in the spectrum of the probe light — incident with ω_1 — with and without the pulses, clearly displaying a blue-shifted peak at ω_2 (red). We fitted the spectra with the theory of light propagation at horizons and found very good agreement (theory fit). We also present the prospect of observing Hawking radiation in this system as well as experimental progress.

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ALIGNMENT OF REFERENCE FRAMES NAD PLATONIC SOLIDS

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The two most commonly used physical systems for the reference frames alignment are: the system of N distinguishable qubits and the system of N qubits in a fully symmetric state. The former are physically equivalent to N spins $1/2$ or polarization states of N photons traveling in separate time-bins and the last to bosonic states, e.g. polarization states of photons traveling in a single time-bin. Much work has been done within the global approach, namely when there is no initial information about reference frame. The optimal states are known for phase, direction and cartesian frame encodings, both when using N distinguishable qubits and when using them in a fully symmetric state or equivalently using a single spin $J = N/2$, see Ref. [1] and references therein. This paper [2] Þlls the missing gap by presenting the optimal state for reference frame alignment within the local approach, when two parties possess some information about the initial orientation and their goal is to measure a small misalignment. The optimal N qubit states featuring highest sensitivity to small misalignment of cartesian reference frames are found using the Quantum Cramér-Rao bound. It is shown that the optimal states are supported on the symmetric subspace and hence are mathematically equivalent to a single spin $J = N/2$. We prove that in the local approach distinguishability of the qubits gives no advantage over the use of N qubits in the fully symmetric state or a single spin $J = N/2$ Ð a fact known for phase and direction reference alignment. Moreover the Majorana representation [3] of spin states is used to reveal a beautiful con- nection between the states optimal for aligning reference frames and the platonic solids. For example the simplest optimal states of $N = 4$ and $N = 6$ qubits correspond to the tetrahedron and octahedron, respectively. The intuitions gained within the Majorana rep- resentation allowed to Þnd the classes of optimal states for higher number N of spins corresponding to each platonic solid.

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ENTANGLEMENT OF QUBITS VIA A NONLINEAR RESONATOR

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Coherent coupling between two qubits mediated by a nonlinear resonator playing a role of a quantum bus is investigated. We show that for some initial states the nonlinearity enhances and for the other decreases the qubit-qubit entanglement. We propose a scheme of an entangler with the nonlinearity controlled by an external parameter e.g. a magnetic flux. Such a scheme allows to extend the number of initial states of the system for which strong entanglement of the qubits can be obtained. The influence of decoherence on the phenomenon is also discussed.

POSITION AND MOMENTUM TOMOGRAPHY

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We illustrate the use of the statistical method of moments for determining the position and momentum distributions of a quantum object from the statistics of a single measurement.

EFFECTIVE ABELIAN AND NON-ABELIAN GAUGE POTENTIALS IN CAVITY QED

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Gauge field theories are natural building blocks when describing subatomic interactions. During the last decades, these have attracted renewed attention; in the end of the 70's it was realized that in the Born-Oppenheimer treatment of molecules effective gauge fields arise [1]. A few years afterwards, Wilczek and Zee showed how similar situations occur for systems changed adiabatically in time [2]. More recently, it has been demonstrated that the motion of ultracold atoms in spatially dependent optical fields renders effective gauge fields [3]. Here, as for vibrating molecules, the origin for the gauge potentials is the adiabatic motion of the particle.

I will show how similar situations appear in cavity QED models, but that the effective gauge fields derive due to entirely different reasons; namely from the phase space motion of quantized cavity fields. In particular, I demonstrate that in a quadrature field representation, the model Hamiltonians can be formulated in terms of effective gauge potentials. Studying three well known models, I display that either Abelian or non-Abelian gauge potentials can be constructed. The purity of these systems, together with high control of system parameters as well as preparation and detection methods, make them promising candidates for experimental detection of non-Abelian dynamics. Indeed, I evidence the non-Abelian characteristics via numerical simulations utilizing experimental parameters.

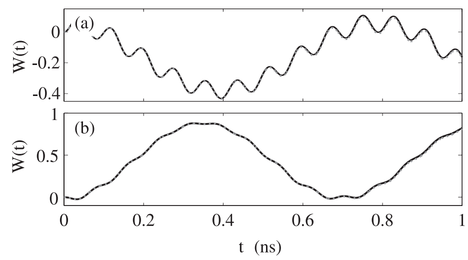

Figure 1: Atomic inversion for a two-level atom interacting simultaneously with two cavity fields. The fields are initialized in coherent states in both plots. The difference between (a) and (b) is solely in the phase of one of the initial coherent states. Due to the underlying non-Abelian structure of the model, this phase difference brings about completely dissimilar dynamics, which is clear from the figure. The parameters are chosen in accordance with the experiment of [4].

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TWO-QUBIT QUANTUM CORRELATIONS VERSUS SINGLE-QUBIT POPULATION

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It is considered a system made by two noninteracting initially entangled qubits, embedded in two zero-temperature bosonic independent environments. It is shown that different forms of quantum correlations for two qubits can be expressed in terms of the excited state population of each single qubit. These relations are explicitly given for both entanglement and Bell function [1]. This permits to evidence regions where there is entanglement without violation of a Bell inequality, showing that entanglement does not necessarily witness the presence of quantum correlations nonreproducible by a classical local model [2].

We finally report the explicit time-dependent relation between quantum correlations dynamics and spectral densities of the environments. To this purpose, we in particular consider systems where non-Markovian features are relevant as in the case of cavity QED systems [3] and of structured environments like photonic crystals [4].

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ROTATING HUBBARD MODEL IN A TRAP

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I study rotational states for trapped bosons in an optical lattice in the framework of the Hubbard model. Critical frequencies are calculated and the main parameter regimes are identified. Two types of transition are observed; one from an edge superfluids to a vortex lattice where the vortices have Mott insulating atoms in the core, and a subsequent transition to a lattice of interstitial vortices, where the superfluid density does not vanish anywhere. The former transition coincides with the Mott transition. Changes in symmetry of the vortex lattices are observed as a function of lattice depth. It is predicted that the different vortex lattice configurations can be identified using time-of-flight techniques.

ROBUST STRATEGIES FOR LOSSY QUANTUM INTERFEROMETRY

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Quantum phase estimation and quantum metrology [1] use quantum effects (such as entanglement or squeezing) to increase the precision in the estimation of physical parameters. Such procedures are in general very sensitive to noise and experimental imperfections: already for low values of the relevant noise parameter, the quantum enhancement typically vanishes. Only recently some quantum optical protocols that are robust to the loss of photons have appeared in the literature [2,3].

In this contribution, we give a simple multiround strategy that permits to beat the shot noise limit when performing interferometric measurements even in the presence of loss. In terms of the average photon number employed, our procedure can achieve twice the sensitivity of conventional interferometric ones in the noiseless case. In addition, it is more precise than the (recently proposed) optimal two-mode strategy [2] even in the presence of loss.

This presentation is based on the paper [4] that has been recently accepted for publication.

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TOWARDS AN EXTENSION OF HUDSON'S THEOREM TO MIXED QUANTUM STATES

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According to Hudson's theorem, any pure quantum state with a positive Wigner function is necessarily a Gaussian state. In addition it is well known that Gaussian states are the only pure states which satisfy the Heisenberg uncertainty relationship. In this talk, recent results [1] are to be presented on the extension of Hudson's theorem to mixed one-dimensional quantum states with a positive Wigner function. These results permit us to reproduce the purity-bounded uncertainty relationship for mixed quantum states [2] and we shed light on the connection of these two fundamental problems.

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INFORMATION AND ENTROPIC CHARACTERISTICS OF PHOTON AND QUDIT QUANTUM STATES

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The probability distribution determining the quantum states of photons and qudits are reviewed. The Shannon, Renyí, and Tsallis entropies associated with the probability distributions are discussed. The Shannon information associated with quantum states in the probability representation is considered. Known inequalities for the classical joint probability distributions determining the quantum states of multipartite systems are discussed in detail and the relation to the inequalities known for quantum von Neumann entropy of the states is presented. Properties of subadditivity and strong subadditivity of the von Neumann entropy of two-partite and multipartite qudit states are considered in view of subadditivity and strong subadditivity properties of Shannon entropies associated with classical joint probability distributions determined the multiqudit quantum states. The new entropic uncertainty relations for optical tomograms are suggested as a test for accuracy of the homodyne measuring the photon Wigner function.

PHOTON NUMBER TOMOGRAPHY AND PHOTON STATISTICS OF GAUSSIAN MULTIMODE STATES

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The photon number tomograms of Gaussian one-mode and multimode states of electromagnetic fields are obtained and expressed in terms of multivariable Hermite polynomials. Statistical characteristics of the photon distribution functions are related to the photon number tomograms of Gaussian states of electromagnetic field. The variances and covariances of the photon probability distributions and photon number tomograms are given in the explicit form and expressed in terms of parameters of the Wigner function of the photon states for all kinds of squeezing and correlations of the quadrature components of the photons in the multimode field. Entanglement and the separability properties of the photon states are formulated in terms of the properties of the photon number tomograms. The violation of uncertainty relation for the photon quadrature variances and covariances is related to the properties of positivity and normalization of the photon number tomogram and photon probability distribution function.

GENERATING “SQUEEZED” SUPERPOSITIONS OF COHERENT STATES USING PHOTON ADDITION AND SUBTRACTION

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We study how photon addition and subtraction can be used to generate squeezed superpositions of coherent states (SSCSs) in free-traveling fields with high fidelities and large amplitudes. It is shown that an arbitrary N-photon subtraction results in the generation of a SSCS with nearly the perfect fidelity $(F > 0.999)$ regardless of the number of photons subtracted. In this case, the amplitude of the SSCS increases as the number of the subtracted photons gets larger. For example, two-photon subtraction from a squeezed vacuum state of 6.1 dB can generate a SSCS of $\alpha = 1.26$, while in the case of the four-photon subtraction a SSCS of a larger amplitude $\alpha = 1.65$ is obtained under the same condition. When a photon is subtracted from a squeezed vacuum state and another photon is added subsequently, a SSCS with a lower fidelity $(F \approx 0.96)$ yet higher amplitude $(\alpha \approx 2)$ can be generated. We analyze some experimental imperfections including inefficiency of the detector used for the photon subtraction.

ENTANGLEMENT OF FORMATION FOR AN ARBITRARY TWO-MODE GAUSSIAN STATE

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We extend to any inseparable mixed asymmetric two-mode Gaussian state (TMGS) the ingenious treatment of Giedke *et al.* for deriving the entanglement of formation for a symmetric TMGS [1]. Instead of the EPR uncertainty $\Delta(1;\rho)$ of a two-mode state ρ, we employ its EPR-like uncertainty

$$\Delta(\alpha;\rho) := \min\left(\frac{1}{2}(\alpha^2+\frac{1}{\alpha^2}), \frac{1}{2}\{[\Delta(\alpha q_1-\frac{1}{\alpha}q_2)]^2+[\Delta(\alpha p_1+\frac{1}{\alpha}p_2)]^2\}\right),$$

where α is an adjustable positive parameter. Such uncertainties have been introduced in Ref.[2] in order to give a separability criterion for an arbitrary TMGS. We prove that, for any given α, in the class of all pure two-mode states having the same value of $\Delta(\alpha;\rho)$, the two-mode squeeze vacuum state (TMSVS) enjoys an important extremality feature: it has the minimal entanglement. Starting from this result we are able to establish for any TMGS a convex decomposition into pure states displaying the least entanglement. Its standard form has been written in Ref.[3]:

$$\rho_G = \int \mathrm{d}^2\beta_1 \mathrm{d}^2\beta_2 P_G(\beta_1,\beta_2) D_1(\beta_1) D_2(\beta_2) \rho_0(r_m) D_2^\dagger(\beta_2) D_1^\dagger(\beta_1).$$

In this optimal expansion, $P_G(\beta_1,\beta_2)$ is a Gaussian weight function, $D(\beta)$ is a Weyl displacement operator, and $\rho_0(r_m)$ is a TMSVS such that for a determined value $\alpha=\alpha_m$ the following condition is fulfilled:

$$\Delta(\alpha_m;\rho_G) = \Delta(\alpha_m;\rho_0(r_m)).$$

It is precisely this property that enables us to prove the formula

$$E_F(\rho_G) = E(\rho_0(r_m)).$$

The equations for evaluating the optimal squeeze parameter r_m are carefully analyzed in Ref.[3].

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SCATTERING APPROACH TO DISPERSIVE ATOM-SURFACE INTERACTIONS

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The quantum fluctuations of the electromagnetic field even in its ground state result in the existence of forces between a neutral ground-state atom and a surface [1]. These forces have been successfully measured using deflection of atomic beams close to surfaces [2], quantum reflection of cold atoms [3] as well as Bose-Einstein condensates (BECs) [4] from surfaces, dipole oscillations of BECs above dielectric surfaces [5]. These achievements have stimulated the development of theoretical models which take into account the conditions of real experiments, and in particular the finite conductivity of the surfaces and the fact that they are not perfectly flat.

We focus here on the geometry corrections for the force acting on a neutral atom in front of a corrugated surface [6]. To this aim, we exploit the scattering approach [7], which was already successfully used to calculate the corrections due to finite conductivity, finite temperature and roughness [8]. After developing the scattering approach for the interaction between an atom and an arbitrarily shaped surface characterized by frequency-dependent reflection operators we present the results for a corrugated plane to first order in the corrugation amplitude. We compute numerically the dispersive potential for arbitrary separation distances and corrugation wavelengths, for a Rubidium atom on top of a silicon or gold corrugated surface. We finally consider the correction to the proximity force approximation [9], and present a very simple approximation algorithm for computing the potential.

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OPTICAL TRAPPING OF A MICROSPHERE PENDULUM

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We present a method to spatially trap the movements of a micropendulum by using optical forces generated by the simultaneous excitation of two optical optical modes of a photonic molecule. We show that the cavity enhanced optical force within the photonic molecule creates an optomechanical potential of depth 5eV and width 10 pm. In our approach, the optical force is assumed to be produced by the symmetric and anti-symmetric modes of the same optical resonance. This is achieved by simultaneous excitation of the system by two-frequency laser light so that one monochromatic component of the light excites the symmetric mode and the second component excites the anti-symmetric mode.

Specifically, we consider an optical system consisting of two microspheres; one is evanescently coupled to an optical fibre carrying the exciting laser field and the other is free to move in space and is considered to be a micropendulum, as illustrated in Fig.1.

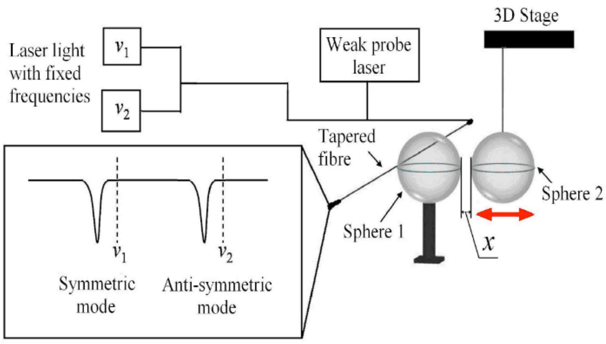

Figure 1: Schematic of the experimental setup. Sphere 1 is fixed and Sphere 2 is a movable pendulum. The inset shows the transmission of a weak probe as a function of frequency for a given separation, x, between the two spheres.

An important feature of this approach is the opportunity it provides to trap the pendulum at any given position in space, since - by a judicious choice of the two frequencies of the laser light - one can predefine the equilibrium position of the pendulum. One application may be in the control of the separation between resonators of a photonic molecule, thus allowing for very fine tuning of the optical modes.

THE ATOMIC ANYON GAS

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Anyons are quasi particles with peculiar properties. They are defined for two dimensional systems. Their quantum statistics is governed by unusual commutation relations where they are neither bosons nor fermions. The anyon can also be described as a particle with a flux tube attached to it. In this work we show how an atomic gas of anyons can be created. The underlying mechanism for creating flux tubes for the ultracold atoms is based on optically induced gauge potentials [1,2]. The technique relies on the interplay between two incident laser beams on the atoms, and the resulting dark state dynamics. We show how an interacting anyon lattice can be constructed which can be used for experimentally simulating the statistical properties of a gas of anyons. The lattice gas is found to be governed by non-trivial long range two-body and three-body interactions in addition to vector type interactions.

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CHARACTERIZATION OF BIPARTITE STATES: FROM THEORY TO EXPERIMENT

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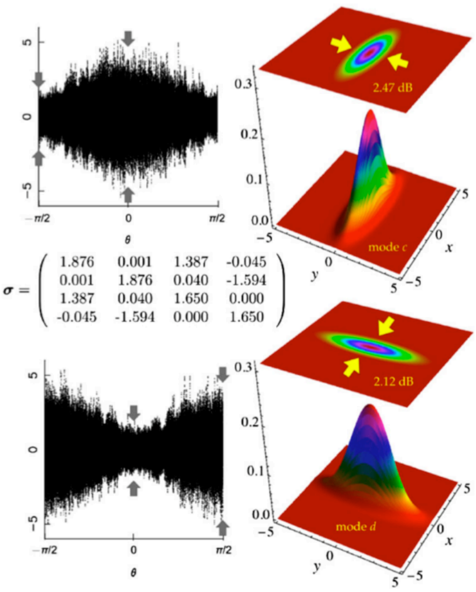
Bipartite light beams endowed with nonclassical correlations are crucial resources for quantum technology and represent a building block for the development of an integrated quantum network. Their full characterization has a fundamental interest in its own and represents a tool for the design of protocols of quantum information processing in realistic conditions. Remarkably, entangled states produced by optical parametric oscillator sources are Gaussian states and thus may be fully characterized by the first two statistical moments of the field modes. In turn, the covariance matrix contains the complete information about entanglement of Gaussian states, *i.e.* about their performances as a resource for quantum technology.

We present the full experimental reconstruction of Gaussian entangled states generated by a type-II optical parametric oscillator below threshold. Our scheme provides the entire covariance matrix using a single homodyne detector and allows for the complete characterization of bipartite Gaussian states, including the evaluation of purity, entanglement, and nonclassical photon correlations, without a priori assumptions on the state under investigation [1,2].



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ENVIRONMENT-DEPENDENT ZENO EFFECTS IN QUANTUM BROWNIAN MOTION

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The theory of quantum information and communication holds the promise of immense computing power beyond the capabilities of any classical computer, it guarantees absolutely secure communication, and it is directly linked to emerging quantum technologies. Currently the key limiting factor in developing large scale quantum computing devices is quantum decoherence, which tends to destroy the relevant physical properties, namely entanglement and superposition between, e.g., two qubits (quantum analogs of classical bits) needed in quantum computing. Decoherence stems from the unavoidable interaction between quantum systems and their environment and as such, is strongly dependent on the form of the environmental spectrum.

Reservoir engineering, which is currently achievable in the trapped ion context [1], offers one way to reduce harmful decoherence effects in a qubit. Another possibility is to make certain types of measurements on the system. If such measurements are conducted at sufficiently short time intervals, the decay dynamics of the system is slowed down. This phenomenon is called the quantum Zeno effect (QZE) [2]. An opposite reaction, namely the acceleration of the decay process is also possible. It is known as the anti-Zeno effect. The occurrence of either QZE or AZE depends on the type of the environment and on the frequency of the measurements.

We have compared the dissipation dynamics of a damped harmonic oscillator in a bosonic environment for three different types of environment, and investigated the connection between dissipation dynamics and the form of the environment spectrum. We have also examined what are the conditions for the occurrence of either Zeno- or anti-Zeno type dynamics. The ultimate goal behind our study is to both shed light on the possibilities of realizing a large scale quantum computing device and to investigate the quantum-classical transition.

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MUTUALLY UNBIASED BASES AND ORTHOGONAL LATIN SQUARES

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Mutually unbiased bases encapsulate the concept of complementarity — the impossibility of simultaneous knowledge of certain observables — in the formalism of quantum theory. Although this concept is at the heart of quantum mechanics, the number of these bases is unknown except for systems of dimension being a power of a prime. We develop the relation between this physical problem and the mathematical problem of finding the number of mutually orthogonal Latin squares. We derive in a simple way all known results about the unbiased bases, find their lower number, and disprove the existence of certain forms of the bases in dimensions different than power of a prime. For these dimensions, the relation between the number of mutually orthogonal Latin squares and the number of mutually unbiased bases is not known and we shall describe few open problems related to this issue.

EXTREME PHASE MEASUREMENTS

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We present quantum phase observables as phase shift covariant normalized positive operator measures. These measures describe realistic direct coherent state phase measurements such as the phase measurement scheme based on eight-port homodyne detection. Phase observables form a convex set and we determine its extreme points, that is, the extreme phase observables [1]. Such observables describe statistics of the pure quantum phase measurements which are free from any classical randomness due to fluctuations in the measuring procedure. Their importance comes from the fact that the statistics of the most precise and informative phase measurement is necessarily described by an extreme phase observable. We generalize the method of finding extremals to other symmetry groups and determine, e.g., extreme position and momentum observables [2,3].

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PHOTON-NUMBER STATISTICS OF TWIN BEAMS AND THEIR NON- CLASSICAL PROPERTIES

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Joint signal-idler photoelectron distributions of twin beams have been measured recently in two different regimes: either the mean number of photon pairs per one pump pulse is considerably lower that the number of independent modes [1] or vice versa [2]. Using the model of superposition of signal and noise we characterize properties of experimetal twin beams in terms of quasi-distributions [3]. Joint signal-idler photon-number distributions are also reconstructed using the method of maximum likelihood. Negative values as well as oscillating behaviour in quantum region are characteristic for the determined joint signal-idler quasi-distributions of integrated intensities. The larger the mean number of photon pairs per mode the weaker the quantum features are. However, they exist even in the mesoscopic regime, i.e. when tens of photon pairs per mode occur on average. Also conditional and difference photon-number distributions have been found to be sub-Poissonian and sub-shot-noise, respectively. Violation of classical inequalities for photocount as well as photon-number distributions has been observed. Criteria of non-classicality of twin beams have been discussed. Also statistical properties of three mesoscopic correlated fields generated in two interlinked parametric processes have been investigated.

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MAXIMUM-LIKELIHOOD ESTIMATION OF STATISTICAL OPERATORS OF FEW-PHOTON STATES

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We deal with the estimation of the state of a d-level system, $d \geq 2$, so called qudit, using measurements of the following operators,

$$\hat{\sigma}_{xjk}, \hat{\sigma}_{yjk}, 1 \leq j < k \leq d,$$

$$\hat{\sigma}_{z,1:j+1}, 1 \leq j \leq d-1.$$

Here

$$\hat{\sigma}_{xjk} = |j\rangle\langle k| + |k\rangle\langle j|,$$

$$\hat{\sigma}_{yjk} = -\mathrm{i}|j\rangle\langle k| + \mathrm{i}|k\rangle\langle j|,$$

$$\hat{\sigma}_{z,1:j+1} = \sum_{j'=1}^{j} |j'\rangle\langle j'| - j|j+1\rangle\langle j+1|,$$

with $|j\rangle$, $j = 1, \ldots, d$, denoting levels of the considered system. Optical qudits can be realized using number states, $|j\rangle \equiv |n = j-1\rangle$. Obviously for $d > 2$ we are left with a somewhat formal generalization of the measurement of the Pauli matrices (operators). We construct the estimator using the maximum-likelihood method. The study of maximum-likelihood estimation of the state of a radiation mode accelerated recently [1, 2].

The optical qubits, qutrits, and qudits in general are superpositions of states with (definite) small numbers of photons. For brevity they are "few-photon states". The maximum-likelihood estimation of a statistical operator may straightforwardly lead to equations, which are conditioned by ranks of the operator we search for. We call it approach I. On the other hand an equation has been derived, which is attractive with its form of an eigenvalue problem (approach II). We treat a relationship between approaches I and II. Approach II includes the possibilities, into which, logically, approach I branches, but (the former) does not guarantee that ranks of the operator we search for need not be taken into account.

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HOW QUANTUM IS THE QUANTUM: GENERAL RESPONSE PROPERTIES OF INTERACTING QUANTUM SYSTEMS

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General response properties of nonlinear interacting quantum systems, bosonic as well as fermionic, are investigated [1]. These analyses give a new perspective to the problem of relations between classical and quantum mechanics.

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STIMULATED RAMAN ADIABATIC PASSAGE ANALOGS IN CLASSICAL PHYSICS

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Stimulated Raman adiabatic passage (STIRAP) is a well established technique for producing coherent population transfer in a three-state quantum system [1-2]. We here exploit the resemblance between the Schrödinger equation for such a quantum system and the Newton equation of motion for a classical system undergoing torque to discuss several classical analogs of STIRAP, notably the motion of a moving charged particle subject to the Lorentz force of a quasistatic magnetic field, the orientation of a magnetic moment in a slowly varying magnetic field and the Coriolis effect. Like STIRAP, these phenomena occur for *counterintuitive* motion of the torque and are robustly insensitive to small changes in the interaction properties.

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EXPERIMENTAL TOMOGRAPHY OF VORTEX FIELDS BY MEANS OF COMPATIBLE MEASUREMENTS

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A novel reconstruction scheme is proposed motivated by the relationship between a von Neumann measurement and a corresponding informationally complete measurement induced on a subspace of the full Hilbert space. This method is utilized for the full experimental tomography of photonic vortex qutrits.

Consider an infinitely dimensional system described by density matrix ρ, and a set of compatible measurements consisting of commuting projectors, $\sum_{n=0}^{\infty} |n\rangle\langle n| = 1$, where $\langle n|n'\rangle = \delta_{n,n'}$. Obviously such a set of measurements is not informationally complete and hence cannot be used to reconstruct the full density matrix ρ of the system. In practice, however, the search is always confined to a small subspace S of the full Hilbert space due to finite computational resources and other reasons. Notice that the original mutually compatible observations act as a POVM in this small subspace: $\sum_n \Pi_S|n\rangle\langle n|\Pi_S = 1_S$, where Π_S is the projector on S. As we show, an informationally complete set of measurements can be generated in this way. Notice that in our approach it is the range of parameters not populated by the system that plays the role of an ancilla. Mathematically speaking the simple von Neumann measurement operates on a *direct sum* rather than *direct product* of the system and ancilla spaces.

The idea can be utilized for the tomography of a vortex field with bounded vorticities. Decomposing the true density matrix in a vortex basis and considering vorticities only up to $\pm S$, even a simple set of mutually compatible measurements may be shown to provide complete information about the measured photon. This will be demonstrated by the full experimental tomography of three-dimensional vortex states from a single transverse intensity scan.

DISSIPATIVE PROCESSES OF A TRAPPED ATOM UNDER EIT COOLING CONDITIONS

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We explore the dissipative force terms which appear in the center-of-mass motion of a trapped atom which is illuminated by two laser beams. The laser parameters are chosen such that the system is driven to electromagnetically induced transparency. In this situation rapid cooling to the ground vibrational level of the trap occurs [1] . Our work aims at resolving the origin of dissipative terms in the interaction of the trapped atom with light. We expected these to appear in the form of Moessbauer-type recoil absorption by the external trap and by spontaneous emission events. Our results indicate that the primary reason for cooling is the AC-Stark shift in combination with an EIT-absorption window which has to be of the order of the trap level spacing in order for cooling to be efficient.

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SPATIAL QUANTUM CORRELATION OF PDC IN A MESOSCOPIC REGIME AND HIGH-SENSITIVITY IMAGING

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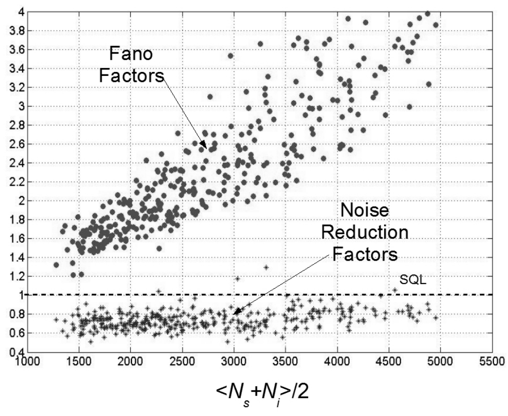
Quantum correlation represents a resource of great importance for the developments of quantum technologies allowing unprecedented results in quantum information, metrology and quantum imaging. An example is the high-sensitivity detection of weak absorbing object proposed in [1], which exploits the intrinsic multi-mode quantum correlations of Parametric Down Conversion (PDC), a result that can have large practical application in biomedical imaging or wherever there is the need of illuminating an object with low photon fluxes.

Here, we present our recent results on this topic. In particular we obtain, for the first time, a clear observation of Sub-Shot Noise spatial correlation in PDC emission (see Fig.1), without any a posteriori correction for the background noise, opening the concrete possibility for realizing high-sensitivity imaging with a sensitivity beyond the Standard Quantum Limit (SQL). Differently with other quantum information protocols that work only in the single photon regime, high sensitivity imaging requires in practise hundreds of photons observed at time, and PDC in high gain regime. This fact, together with the use of a CCD camera for measuring the spatial correlations, leads to interesting new measurement schemes and problems that are discussed in detail.

Furthermore we present our first efforts in realizing a real high sensitivity imaging experiment, placing a weak absorbing mask (with a non banal spatial structure) in one branch of PDC and subtracting the noise measured on the other branch.

Fig.1: Noise reduction factor $\sigma \equiv \langle \delta^2(N_i - N_s) \rangle / \langle N_i + N_s \rangle$ evaluated over an ensemble of pixel pairs. $N_{s(i)}$ is the number of photons measured by a single pixel in the signal(idler) arm. Values of $\sigma < 1$ indicate that the correlation in the photon numbers collected by pairs of correlated pixel in the same image (single shot) is well below the SQL.



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ATOM DIODE: A LASER DEVICE FOR A UNIDIRECTIONAL TRANSMISSION OF GROUND-STATE ATOMS

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We will give a review about the "atom diode", a laser device that lets a ground-state atom pass in one direction but not in the opposite direction. We will show different schemes which have been theoretically developed to implement such a device [1-6]. New methods for cooling atoms based on an atom diode have been proposed and will be presented [7-8]. Recent experimental implementations [9-10] will be overviewed as well as the connection between an atom diode and the Maxwell demon will be discussed [11-12].

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BUILDING A HIGH-FINESSE OPTICAL RESONATOR OF VARIABLE LENGTH FOR NONLINEAR CAVITY QUANTUM ELECTRODYNAMICS

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Strongly coupling atoms to the light field of a high-finesse optical resonator is a key ingredient to study light-matter interaction at the single quantum level. Recent experiments have demonstrated that such a system exhibits a non-linear intensity response when a single atom is made to interact not with one, but with two photons at the same time [1]. Due to the anharmonicity of the energy-level structure of this system a selective excitation of a two-photon resonance is possible. Here the system absorbs and emits photons in pairs. Employing this scheme we were able to show how a random stream of incoming photons is transformed into a correlated stream of output photons [2].

We are currently constructing an improved experimental setup in which we are using coned mirrors, permitting optical access in the plane perpendicular to the cavity axis. This enables the use of transverse excitation and probing schemes from the side. It also becomes possible to exploit radial cooling mechanisms [3]. This leads to an improvement of the three-dimensional confinement of the atom and a significant increase in storage time. In addition, one of the mirrors is mounted on a custom-built translation stage connected to an inch-worm motor. By that the cavity length can be tuned from less than 50 μm up to 10 mm.

Variation of the cavity length also alters the cavity line width as well as the coupling strength and thus permits to work in different coupling regimes. Furthermore the longer storage times in combination with a new detection scheme pave the road to measure higher-order correlation functions important to gain new insights into the nonlinear response of the coupled atom-cavity system. This opens up a complete set of interesting, new experiments on the fundamental interaction of light and matter.

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QUANTUM FRICTION FORCES ON POLARISABLE ATOMS AND MOLECULES

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Polarizable atoms and molecules experience the Casimir–Polder force near magnetodielectric bodies, a force that is induced by vacuum fluctuations of the electromagnetic field that are altered by the presence of the magnetodielectric material. This force is well understood for atoms and molecules at rest and can be easily derived withing the framework of macroscopic quantum electrodynamics [1,2].

Atoms and molecules in relative motion to the magnetodielectric surface experience an additional force parallel to its direction of motion. This effect is commonly known as quantum friction [3]. We present a full quantum-mechanical treatment of this force and show that, for atoms or molecules in electronically excited states, both decelerating as well as accelerating forces can occur. The friction force changes sign depending on the magnitude of the relevant internal atomic transition frequency ω_A relative to the frequency ω_s of the surface plasmon to which the atom couples.

Magnetodielectric properties of a material can be tailored very effectively by structuring surfaces on the nanometer or micrometer scale. Structures of the size of the relevant wavelength such as microresonators are capable of tailoring the local density of states for the propagation of particular light modes. It is therefore conceivable that the resonant enhancement of the local density of modes (and hence the coupling strength to a particular surface plasmon) will be translated into an enhancement of the friction force.

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RECURRENCES IN QUANTUM WALKS

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Recurrence in the dynamics of physical systems is an important phenomenon with many far reaching consequences [1]. For random walks the recurrence is characterized by the so-called Pólya number which denotes the probability that the particle returns to the origin at least once during the whole time evolution. If the Pólya number equals one the walk is called recurrent, otherwise there is a non-zero probability that the walker never returns to its starting point. Such walks are transient. Pólya [2] proved that one and two-dimensional walks are recurrent while for higher dimensions the random walks are transient and a unique Pólya number is associated to them in each dimension.

In [3] we have extended the concept of Pólya number characterizing the recurrence of random walks to the quantum domain by a specific measurement scheme. We have shown that the Pólya number of a quantum walk depends in general on the choice of the coin and the initial coin state, in contrast to the classical walks, where the Pólya number depends on the dimension.

In the present contribution we analyze the recurrence of several types of quantum walks [4]. We illustrate on several examples that one can achieve strikingly different recurrence behaviours for quantum walks. First, we show that for the class of quantum walks driven by tensor-product coins the Pólya number is independent of the initial conditions and the actual coin operator, thus resembling the property of the classical walks. Second, we analyze the 2-D Grover walk, which exhibits localization and thus is recurrent, except for a particular initial state. We employ the Grover walk to show that one can construct in arbitrary dimension a quantum walk which is recurrent. This is in great contrast with the classical walks which are recurrent only for the dimensions d = 1; 2. Finally, we analyze the recurrence of the 2-D Fourier walk. This quantum walk is recurrent except for a two-dimensional subspace of the initial state.

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EXPERIMENTAL REALIZATION OF BASIC QUANTUM ALGORITHMS USING A 3-QUBIT REGISTER IN DIAMOND

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One of the major candidates for a potential room temperature quantum processor is the NV center in diamond. Due to the possibility to control and read out single electron and nuclear spins individually spectacular experiments like the implementation of a conditional two-qubit CNOT gate and creation of multipartite entanglement [1] have been demonstrated recently. Because of the extremely long coherence times different Bell states can be tranformed into another and the entanglement can be used to perform simple quantum algorithms. The nulcear spins of two ^{13}C atoms and the electron spin of the NV-center itself compose a 3-qubit quantum register. Using this register we show first steps to perform algorithms similar to superdense coding and Deutsch-algorithm under ambient conditions.

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EXPONENTIAL SUMS ALGORITHM BASED ON OPTICAL INTERFERENCE: FACTORIZATION OF DIFFERENT NUMBERS IN A SINGLE RUN

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The factorization of a number N is a lot more difficult than the reverse operation of multiplying prime numbers. A famous quantum algorithm for factorization was invented by Shor in 1994, but so far it has not been implemented for factorizing numbers larger than 15. For this reason, more recently, a classical approach to factorization, was proposed by Schleich and coworkers, exploiting the periodic properties of truncated exponential sums [1] of order j, with M terms. Truncated exponential sums of order $j = 2$ (Gauss sums) have been reproduced, using different techniques [2-6]. Anyway no one of the past realizations allow to achieve a real factorization procedure. For real factorization we mean: no calculation of the ratio between N and the possible trial factors l before the experiment is run; determination of the factors in only a single run of the experiment; use of the same analogue computer (experimental setup) for the factorization of different numbers N.

In this talk, we will show the experimental proof of principle, for $N = 143$ of a new factorization algorithm, which allows to overcome all the drawbacks in the past realizations. This algorithm is based on the implementation of generalized continuous truncated Gauss sums, generalizable to higher order $j > 2$, using an M-path symmetric Michelson interferometer in free space, with variable interfering optical paths. The factors correspond to the wavelengths which allow constructive interference and so maxima in the extrapolated intensity spectrum.

The experimental result is impressive: only using $M = 3$ interfering paths, we have determined, in only one run of the experiment, the two factors $l = 11, 13$ of $N = 143$, corresponding to constructive interference in the experimental diffraction pattern, which is in a pretty good accord with the expected theoretical pattern. Moreover, a rescaling procedure allows us to factorize different numbers N', exploiting all the maxima in the same intensity spectrum.

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SUDDEN BIRTH AND DEATH OF ENTANGLEMENT OF TWO ATOMS IN A FINITE TEMPERATURE RESERVOIR

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The dynamics of two entangled qubits in a noisy environment have been a subject of intensive investigations in recent years (see review [1]). It turned out that for two qubits initially entangled and each qubit interacting with its own reservoir, the entanglement can disappear in a finite time, despite the fact that all the density matrix elements, including atomic coherences, disappear only asymptotically [2,3]. Yu and Eberly [2] introduced for this unusual behavior the term “sudden death of entanglement”.

The evolution of two two-level atoms interacting with a common reservoir can be different from the case of independent reservoirs. In the common reservoir the atoms behave collectively. Such a collective behavior leads to some unusual features, for example, entanglement can be created between the qubits by the spontaneous emission [3]. It has been shown also that after “sudden death of entanglement” it is possible to observe the revival of entanglement [4]. Moreover, the process opposite to the sudden death of entanglement, the “sudden birth of entanglement” can be observed [5]. After a finite time of evolution without entanglement, suddenly the two qubits become entangled.

In case of two two-level atoms interacting with a common reservoir, the evolution of the system is described by the Markovian master equation. The solutions to the master equation allow for the detailed discussion of the entanglement evolution. Here, we want to discuss the effects of finite temperature of the reservoir on the phenomena of sudden birth and death of entanglement.

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COLLISIONAL SHIFTS IN THE MAGNETIC RESONANCE OF COLD ATOMIC HYDROGEN GAS

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We present experimental studies of electron spin resonance (ESR) line shifts due to collisions in a cold (T<0.5 K) gas of atomic hydrogen. Experiments were performed in a strong magnetic field of 4.6 T on a two-dimensional H gas adsorbed on the surface of superfluid helium film [1] and on a 3D gas compressed to densities of $n \sim 10^{18}$ cm^{-3} [2]. In both cases the gases were non degenerate, but well in the cold collision regime, where $n^{-1/3} >> \Lambda_{th} >> a$, with$\Lambda_{th}$ being the thermal de-Broglie wavelength and a the s-wave scattering length. In this regime the effects of the indistinguishability of the colliding atoms impose certain restrictions on the scattering properties.

We found that the cold collision shift of the ESR lines is negligibly small in doubly polarised (both electron and nuclear spins) H gas compared to a mixture of two hyperfine states. This difference can be explained by properly taking into account the effects of quantum statistics in atomic collisions and the magnetic dipolar effects. We report on the first direct measurement of the difference between the triplet and singlet s-wave scattering lengths, $a_t - a_s = 60(10)$ pm, which is in agreement with existing theories [2].

We propose new measurements of the cold collision shifts in H gas, which would allow a better characterisation of the interaction parameters and help in refining the calculations of the interaction potentials between atoms.

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ENTANGLED STATES OF A PHOTON-ELECTRON SYSTEM

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In the present contribution we discuss entanglement of two different kinds of interacting particles; photons and electrons. It is proved that the most fundamental interaction in quantum electrodynamics — namely the interaction of a free electron with a mode of the quantized radiation field — leads quite naturally to the generation of a class of photon number-phase minimum uncertainty states. It is shown that from the entangled photon-electron states developing from a highly excited number state due to the interaction with a Gaussian electronic wave packet, the minimum uncertainty states of Jackiw's type [1] can be constructed. In the electron's coordinate representation the physical meaning of the expansion coefficients of these states are the joint probability amplitudes of simultaneous detection of an electron and of a definite number of photons. The photon occupation probabilities in these states preserve their functional form as time elapses, but their sizes depend on the location in space-time of the detected electron. An analysis of the entanglement entropies derived from the true photon number distribution and from the electron's density operator is given [2].

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SOME ASPECTS OF NONCLASSICAL LIGHT PROPAGATION IN BOUNDED MEDIA

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Here we present the new method of description of light propagation in bounded media. Our approach is based on property of photon Green's function to split up into parts corresponded to medium- and vacuum-induced contributions to the field-field fluctuations. These contributions enter the physics of emission and absorption in a completely different way. Whereas the medium-related ones are well known from the optical theorem for bulk media [1], [2], the vacuum-related contributions are more subtle ones and depend on boundary conditions. We have shown that the vacuum-induced fluctuations describe propagation of arbitrary, even nonclassical light in terms of solutions of the classical wave propagation problem. These results apply independently of specific optical properties or geometrical shapes of the matter for arbitrary nonequilibrium situations.

As an example the transmission of optical field in squeezed vacuum through a semiconductor slab is given and compared with results which were obtained with the help of the input-output formalism [3]-[6]. The latter formalism neglect spatial dispersion and assume normal incidence of electromagnetic waves on boundary surfaces of a slab. In contrast, the present approach yields exact results without these restrictions. Here we also discuss the influence of nonclassical radiation on electron-hole kinetics. We derive an expression for dielectric function that accounts self-energy contributions due to the polarization of a media by squeezed light.

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COHERENT POPULATION TRAPPING BY OPTICAL FREQUENCY COMB

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The quantum interference between excitation pathways can eliminate the absorption at the resonant frequency of an atomic or molecular transition in gas medium, through the preparation of "dark states" that are immune to excitation. Such phenomenon, the so-called coherent population trapping (CPT) [1], can be observed in a system in which the two hyperfine components of the $S_{1/2}$ ground state of an alkali atom are coupled to a common excited state by two laser fields. If the frequency difference of the laser fields is close to the atomic hyperfine splitting ω_{12} the quantum coherence between the two hyperfine components is created, which leads to enhanced transmission of the optical fields in a narrow resonance around the difference frequency of the two optical fields. CPT resonances have recently been used for the slowing of light, storage of quantum information, magnetometry and in metrology. To provide two optical fields with a frequency difference equal to ω_{12} one must use modulation techniques involving microwave radiation. An effective modulation of laser radiation with a few GHz modulation frequency is still a challenging problem. Since 1999 one of the hot topics of physics research has been the study of an optical frequency comb which is an optical spectrum comprising a set of equidistant discrete frequency components. To generate a frequency comb, a mode-locked laser can serve very well: the optical spectrum of a periodic pulse train, as generated in a mode-locked laser, consists of discrete spectral lines with an exactly constant spacing equal to the pulse repetition frequency. Nowadays, frequency combs are widely used for metrology purposes, mainly for the measurement of absolute optical frequencies [2]. A frequency comb has potential use also as a source of equidistant optical frequency components in experiments dealing with the coherent interaction of light with matter. Let us consider the laser frequency comb overlapping with the absorption line of a three-level system and the frequency separation Δ of the comb components is chosen in such a way that $N\Delta \simeq \omega_{12}$ and N is a large integer. One can expect that there will be CPT resonances if the frequency Δ is tuned to exact two-photon resonance $\Delta = \omega_{12}/N$ [3].

We present a theoretical analysis of the CPT resonances excited by frequency comb including modelling of the short laser pulses interaction with ^{87}Rb vapour. The model takes into account interaction of atoms with a train of femtosecond pulses or pulses generated by a frequency-shifted feedback laser. As a model of the atom, a four-level system of the Rb atom was chosen. The two lower levels of the system are the two hyperfine components of the ground state; the third level is one of the hyperfine components closest to two Fourier components of laser radiation, coupling it with the lower levels. The other components of the ground state, that practically do not interact with laser radiation, are taken into account as the fourth level (a bath), which is populated due to atom's spontaneous emission from the higher level. The solutions of the master equations were obtained in two ways: (i) numerical integration of differential equations during the time interval greater than the maximum relaxation time in the system; and (ii) finding stationary solution of equations for Fourier-components of the density matrix elements. The results from both methods coincide with the calculation precision.

Comparison of the results of the atom interaction with the femtosecond laser and with the frequency-shifted feedback laser shows that CPT resonances are more pronounced in the first case, especially when Rb vapour with a buffer gas is used, though the difference is not large enough to choose one over the other. The theoretical modeling with realistic parameters shows that the width of the CPT resonances can be less than 30 KHz. A more precise estimation of the resonance width was limited by minimal frequency step inherent in to the equation's solution algorithm.

An experimental study of the magneto-optical CPT resonances in ^{87}Rb and ^{85}Rb fluorescence, excited by the femtosecond Ti:Sa-laser radiation resonant with D_2 line has been performed. In the experiments, the CPT resonances were detected as narrow dispersion shape features in the output of the lock-in amplifier which detects the amplitude of the first harmonic in the fluorescence signal in the presence of axial magnetic field, modulated with small amplitude at low frequency as a function of this field dc component. The experimental results show that these resonances can be detected with high signal to noise ratio, and their characteristics are well described by the developed theoretical model.

The CPT resonances in ^{87}Rb and ^{85}Rb fluorescence, excited by the frequency shifted feedback diode laser with extended cavity resonant with D_2 line has been observed. These resonances were detected as narrow dips in the fluorescence signal as a function of the acousto-optic modulator driving frequency. The preliminary experimental results show that these resonances can be detected with high signal-to-noise ratio, their characteristics are well described by the developed theoretical model.

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TYPICALITY OF INTERFERENCE PATTERNS BETWEEN INDEPENDENT BOSE GASES

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Interference of atomic gases released from two independent Bose-Einstein condensates was observed in an excellent experiment by Andrews *et al.* [1]. Javanainen and Yoo argued in their pioneering work [2] that even when no first-order interference is expected interference fringes can show up in a snapshot, by recording all the positions of individual atoms. Such an interference pattern with a definite fringe spacing is *almost surely* observed in a snapshot, provided the number of the atoms in the clouds is very large, although the phase of the interference pattern can change from snapshot to snapshot. The idea of this "measurement-induced interference" has been explored for a decade [3].

We present a novel scheme to study the measurement-induced interference for generic setups. The idea is to extract "sinusoidality" of the profile of overlapping gases, *irrespective of the phase* of a possible interference pattern. We then check that the sinusoidal patterns appear with high probability and are *typical* among all the possible snapshot profiles.

Our framework allows us to discuss the measurement-induced interference without computing the N-particle distribution with a large number N of the involved atoms. The appearance of the interference fringes is shown to be ruled by the two-particle distribution (HBT correlation), and the typicality is governed by the four-particle distribution.

While we demonstrate how our formalism works with Javanainen–Yoo's model with plane waves [2], our concise set of tools enables us to study more realistic setups: we analyze the time evolution of the interference fringes produced between two independent expanding clouds of non-interacting atoms, released from spatially separated traps. Arbitrary states of the clouds can be implemented and we investigate the interference between two independent thermal gases released from spatially separated harmonic traps. All these analyses are done analytically and do not require numerical simulation.

It is shown that the interference fringes evolve in time like those observed in the Young-type interference of two waves with a fixed relative phase. The importance of the initial size of the clouds for a high fringe contrast is highlighted.

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CONTROL OF QUANTUM FLUCTUATIONS IN SPONTANEOUS PATTERN FORMATION

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Nonlinear optical cavities are known to generate intense non classical states of light, ranging from squeezed states to twin beams. In some cases, quantum correlations appear not only in the whole beam but also when only a spatial component of the beam is detected [1]. Applications of spatial quantum correlations in parallel communications and imaging have been demonstrated [2].

In the last decade, spatial quantum correlations have been studied also in the context of complex systems. Self-organization and spontaneous pattern formation in optics are indeed often associated to quantum effects, as predicted, for instance, in light patterns emitted by parametric oscillators and Kerr cavities. In this work we show the role and the importance of the use of photonic crystals in a prototype nonlinear cavity, a type I optical parametric oscillator, to control not only the macroscopic transverse profile of the emitted light beam but also its quantum fluctuations.

In a recent paper we demonstrated that photonic crystal introduces a modulation in the transverse profile of the beam that can inhibit spontaneous pattern formation [3]. Here we show that in the OPO the instability threshold can be either increased or lowered. We discuss the possibility to use photonic crystals to engineer spatial quantum phenomena such as anti-bunching and EPR entanglement. The use of the Q representation [4] allows to describe quantum fluctuations in the OPO below and above the signal generation threshold.

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Posters

EXPERIMENTAL REALIZATION OF POST-SELECTION REDUCTION OF NOISE

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We have studied the ability of interference of signal photon in the presence of environmental photon. To simulate and qualify this effect we used Mach-Zehnder (MZ) interferometer. Signal and noise photons were generated by type-I spontaneous parametric downconversion process in a nonlinear crystal. One photon, signal photon, from each photon pair interfered in MZ interferometer and the other photon was coupled to one arm of the interferometer as a noise. In the experiment the only parameter that determined a degree of correlation between signal and noise photons was a time overlap of their wavepackets. All other characteristics were identical. We measured the influence of the presence of noise on the visibility of interference in two limit cases. In the first case signal and noise photons were completely distinguishable and in the second case they were completely undistinguishable. Then we investigated a possibility of increasing the reduced visibility of interference by an additional postselection measurement. A fraction of signal was separated from the interferometer arm with noise and detections at the outputs of MZ interferometer were counted in coincidence with detections at this additional output. We achieved a complete compensation of influence of noise in the case when signal and noise photons were undistinguishable and partial increasing of visibility in the case of distinguishable photons.

FEATURES OF LASER STIMULATED BREMSSTRAHLUNG IN QUANTUM FIELD

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Modern experimental laser physics makes possible to create and investigate states of quantized field that differ dramatically from the classical field states. One of the most interesting cases is the "squeezed vacuum" state of electromagnetic field. Latest experimental and theoretical opportunities make the problem of interaction of non-classical light with medium very important. Many interesting phenomena arise due to interaction of strong laser field with atomic and molecular structures: ATI, field-induced electron-ion scattering and recombination, etc. Many of these processes had been investigated in details, but new properties of considered phenomena can be found in the case of interaction with quantized electromagnetic field. Peculiarities of quantized field states can lead to significant difference in the field-matter interaction in comparison with the same processes in a classical field.

In this work the process of the field assisted Bremsstrahlung was investigated in the case of quantized electromagnetic field. This effect consists in the field-stimulated electron-ion scattering accompanied by emission or absorption of several photons by the electron during the recollision. To describe this problem the non-stationary Schroedinger equation for the electron scattered on the potential center in the presence of quantum electromagnetic field is solved analytically in the frame of the perturbation theory with electron-field interaction considered in the dipole approximation. The basis of the "dressed" states for a free electron in a quantized field [1-3] similar to the well-known semi-classical Volkov states was used to solve the problem. Since the interaction with the field was taken into account explicitly all the multiphoton processes are considered directly.

The regimes of the field-stimulated Bremsstrahlung are investigated for different initial states of quantized field, including sufficiently non-classical state of "squeezed vacuum" and for different averaged numbers of photons. Different channels of absorption and emission of the field quanta during the scattering process was investigated in the case of Fock, coherent and "squeezed vacuum" initial field states. The electron energy spectra and the final distribution over different photon states for the quantum field was obtained. The semi-classical limit to the Bunkin-Fedorov result [4](that was obtained later in Kroll-Watson theory[5]) was obtained for analytical solutions in the case of coherent initial state of field and very large average number of photons. The stimulated processes are compared with the spontaneous emission of photons by the electron during scattering.

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ANALYSIS OF SURFACE PLASMON THEORY USING BLOCH'S HYDRODYNAMIC MODEL

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In this study, the Surface Plasmon (SP) theory is analyzed using Bloch's hydrodynamic model [3]. The theoretical and experimental researches on the SP theory are held in the frequency range around plasmon frequency and in these researches, Drude model is mainly used to characterize metals. However, Drude model is not sufficient to predict the behavior of metals at higher frequencies. At this frequency range, atomic level interaction can not be negligible so a more realistic model that models the matter as fluid and covers the cumulative interaction between atoms located in different positions is needed. In this paper, we reanalyze the transmission behavior of light through a nano-slit embedded in a metal layer. We model the dielectric constant of the metal with Bloch model instead of conventional Drude model. Therefore the coupled effect of matter and wave to one another which is missed in studies using Drude model can now be counted in. SP theory is restudied and the dispersion relation of SP is revised with hydrodynamic model. The new contribution brought by Bloch model is underlined and suggestions for new possible applications are made.

Effective refractive index of the slit that relates surface plasmon wavevector generated by the slit to the wavevector of the wave incident to the slit region is calculated by hydrodynamic model [2]. After defining the effective refractive index of the slit, the transmission behavior of light trough it is analyzed by hydrodynamic model [1]. The enhanced transmission of light issue reinvestigated through analytical studies and simulations.

Bloch model has a control parameter which depends on the electron density of the metal and with this parameter, we have the ability to modify the transmission behavior of the light through the slit. This control parameter can be modified by varying the physical circumstances i.e. temperature. The amplitude of the transmitted wave can be enhanced by modifying the control parameter of Bloch model. The phase of the transmitted wave can be controlled by this parameter and this result could be used in the experimental studies on the phase issue [4].

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HYDRODYNAMIC THEORY OF GIANT VORTICES IN TRAPPED FERMI GASES

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The rotational properties are studied for a unitary superfluid gas of fermions at zero temperature. Using a hydrodynamic approach, the conditions for the formation of a giant vortex are discussed. It is found that in the present approximation, an anharmonic addition to the usual harmonic-oscillator type of trap potential is necessary for the energetic stability of a giant vortex. To determine the conditions quantitatively, a Thomas-Fermi approach is compared with numerical solutions in three dimensions.

JOSEPHSON OSCILLATIONS IN A FINITE TEMPERATURE BEC

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We address the issue of thermal effects on the relative phase and atom number in a double well Bose-Einstein condensate (BEC). In particular, we perform numerical simulations to study the Josephson oscillations and the self-trapped state of two weakly linked condensates with parameters corresponding to the experiment by Albiez *et al.* [1]. In this experiment a gas of 1150 Bose-Einstein condensed Rubidium atoms is trapped in a double well potential. The system is excited from the ground state by creating an imbalance in the atom number between the two wells. If the initial population imbalance is relatively small, the dynamics results in Josephson (tunneling) oscillations. On the other hand, if the initial population difference is relatively large, the system exhibits self-trapped behaviour where the population difference is locked to oscillate around a nonzero value.

In the work presented here, we focus on the damping arising from the presence of a thermal cloud of non-condensed atoms. Our numerical method consists of solving a generalized Gross-Pitaevskii (GP) equation for the condensate and a semiclassical kinetic equation for the thermal cloud. In the Josephson regime we find temperature dependent damping in the population imbalance and in the relative phase. We also explore the effect of thermal atoms on the self trapped condensate and see that after a finite time the self trapping transforms into ordinary Josephson oscillations. Finally, the possible dissipation mechanisms and their role in the observed damping is discussed.

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QUANTUM ELECTRODYNAMICS IN ABSORBING NONLINEAR MEDIA

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The effects of lossless dielectric media, described by a real susceptibility, on an applied electric field have been studied at length both classically and in the framework of quantum optics. However, it can be shown that any causal response function, such as the susceptibility, is necessarily complex, with the real and imaginary parts related by the Kramer-Kronig relations. Hence absorption, which is associated with the imaginary part of the susceptibility, is an unavoidable effect in causal dielectrics. The inclusion of absorption into a quantum description of matter assisted electromagnetic fields provides a rich area for new phenomena. A quantum field theory approach to linear optics in absorbing media has been known for sometime and involves expanding the electric field in terms of the classical Green's tensor and fundamental bosonic fields [1,2]. This approach has proved successful in describing many linear optical processes. More recently attempts have been made to extend this approach to non-linear media [3,4]. Here were present current work on the derivation of an effective Hamiltonian for the two photon nonlinear process of parametric down conversion. The resulting Hamiltonian indicates the existence of new noise field interactions which are not present in the standard descripton of nonlinear optics, such as the ability for pump photons to down converting to one or no photons with the associated appearence of one or two noise field excitations respectively. These absorptive processes have the potential to put serious limits on the ability to produce strongly correlated photon pairs for quantum information processing and quantum computational applications.

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MULTIPARTITE ENTANGLEMENT IN PARAMETRIC DOWN-CONVERSION WITH SPATIALLY-STRUCTURED PUMP

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Until recently, most investigations of multipartite entanglement have been concerned with temporal modes of the electromagnetic field, and have neglected its spatial structure. Emergence of the area of quantum imaging naturally raises the question about a possibility of entangling at the same time several spatial modes of the electromagnetic field. We present a simple model which allows one to generate multipartite entanglement between several spatial modes, and investigate the characteristics of this entanglement. We start with the simplest case of three-partite entanglement which can be produced in parametric down-conversion with two symmetrically-tilted plane waves serving as a pump. Then we demonstrate that our scheme can be easily generalized to N-partite entanglement using N symmetrically-tilted plane waves for pumping a parametric medium.

REALISTIC QUANTUM TELEPORTATION WITH NON-GAUSSIAN RESOURCES

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We investigate the effects of losses and noise on the performance of non-ideal quantum teleportation implemented with non-Gaussian resources. The main decoherence mechanisms of the non-ideal teleportation protocol are the photon losses occurring in the realistic Bell measurements, and the noise arising in the propagation of optical fields through fibers. First, we extend the characteristic function formalism [P. Marian and T. A. Marian, Phys. Rev. A **74**, 042306 (2006)] to this realistic framework. Next, by exploiting displacement strategies, we analytically compute the success probability of teleportation for input coherent states with squeezed Bell-like states and squeezed cat-like states used as entangled resources. At fixed squeezing parameter, and at given experimental parameters describing the inefficiencies of the non-ideal protocol, the optimization procedure is carried out on the free available parameters of the non-Gaussian resources. Notwithstanding a certain degree of suppression of the fidelity, it is found a remarkable enhancement in the efficiency of the teleportation with non-Gaussian resources with respect to Gaussian ones also in realistic conditions. Partial information on the alphabet of input states allows a further improvement of the performance.

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EXTREMAL QUANTUM CHANNELS FOR A GENERAL SYSTEM

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Quantum channels can be mathematically represented as completely positive trace-preserving maps that act on a density matrix. A general quantum channel can be written as a convex sum of 'extremal' channels. We show that for an N-level system, the extremal channel can be characterized in terms of N^2-N real parameters coupled with rotations. We give the representation for N= 2, 3, 4. A quantum channel can be further classified into Unital (center preserving) and Non-Unital channels. We discuss how the extremal maps differ in the two cases. Finally, we note some similarities between N=2 and N=4 level systems under a Unital channel.

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QUDIT AND LIGHT STATES: PECULIARITIES OF THE TOMOGRAPHIC-PROBABILITY REPRESENTATION AND THE QUBIT-PORTRAIT METHOD

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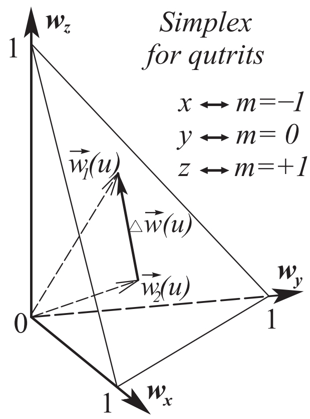
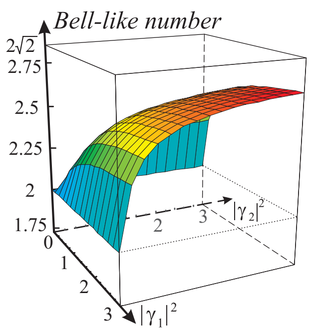
Apart from being described by the density matrix ρ, any state of a qudit can be represented by the tomographic-probability-distribution function $w(m,u) = \langle m|u\rho u^{\dagger}|m\rangle$, where m is the spin projection ($m = -j, -j+1, \ldots, j$) and u is a unitary $(2j+1) \times (2j+1)$ matrix of irreducible representation of the rotation group $SU(2)$ (one could also use the special unitary group $SU(N)$, with $N = 2j+1$). The Hilbert-Schmidt distance $\|\rho_1 - \rho_2\|$ between states ρ_1 and ρ_2 is related to the distance between their tomograms [1,2]

$$\|\Delta\vec{w}(u)\| = \left[\frac{1}{2}\sum_{m=-j}^{j}\Big(w_1(m,u) - w_2(m,u)\Big)^2\right]^{1/2}$$

as follows $\|\rho_1 - \rho_2\| = \max\limits_{u\in SU(N)} \|\vec{w}_1(u) - \vec{w}_2(u)\|$.



Similarly to the qudit case, any light state is described by its photon-number tomogram. The entanglement of two-mode light states can be detected by using a linear map of the photon-number tomogram with infinite outputs onto qubit tomogram [3] (qubit portrait). Such a procedure results in reducing the separability property of a two-mode light state to the Bell-CHSH inequality for two qubits. As far as there exist many ways to construct the qubit portrait, some examples of them are considered: (i) by splitting states with no photons and with nonzero number of photons in each mode; (ii) by splitting states with even and odd numbers of photons in individual modes. The violation of the Bell-CHSH inequality for the Schrödinger cat state of the form $|\gamma_1,\gamma_2\rangle + |-\gamma_1,-\gamma_2\rangle$ is depicted in figure ("even-odd" method).



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OFF-RESONANT QUANTUM ZENO AND ANTI-ZENO EFFECTS ON THE ENTANGLEMENT

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We examine the appearance of Zeno and anti-Zeno effects [1-2] in the entanglement dynamics of two qubits off-resonantly coupled to the same lossy cavity (working as a common structured reservoir), when the unitary evolution of the system is interrupted by repeated projective measurements. We describe in detail these quantum effects, by comparing the measurement induced coarse grained dynamics to the entanglement evolution in the absence of measurement in several scenarios [3]. In particular, we examine strong and weak coupling regimes, the role of the relative coupling strengths between the two qubits and the reservoir, the effect of detuning from the main cavity frequency. We show that the anti-Zeno effect can occur in the entanglement dynamics when, for fixed time interval between successive measurements, the qubits frequencies are detuned from the main reservoir frequency. Furthermore, Zeno and anti-Zeno effects can even appear sequentially many times as a function of the interval between measurements. Finally we show that, in the off-resonant regime, we can preserve the entanglement using the quantum Zeno effect better than in the resonant limit [4], even if, in this case, no sub-radiant state exists.

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ADAPTATION OF NOISY QUANTUM CHANNELS

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Quantum entanglement plays important role in various branches of quantum information science such as quantum key distribution [1]. Propagation of quantum entanglement is represented by quantum channel - completely positive trace preserving map. Quantum channel influences the propagating entangled state and recently there has been reported channels for which the entanglement is totally lost [2]. This phenomena has been called sudden death of entanglement.

Precisely, by sudden death of entanglement is meant a finite-time continuous disentanglement of some input generally non-maximally entangled state. We may, for broad class of real physical situations, divide the sudden death scenario into two steps: first we create a non-maximally entangled state from a maximally entangled state using a subsequent quantum channel and second we send the prepared non-maximally entangled state to another quantum channel (assuming the channels have mutually independent reservoirs). Optimizing over input maximal entangled states we can recognize whether the concatenated channel is actually entanglement breaking or not [3].

We assume qubit entanglement with local unitary quantum dynamics meaning that each qubit interacts just with its own reservoir resulting in channels for which Kraus representation is valid. For this kind of qubit quantum channels we propose a probabilistic adaptation method by introducing a single-copy quantum filtering operations applied between the channels [4]. The adaptation method differs from the known single-copy distillation procedures [5] in that the adaptation quantum filter parameters depend not only on the previous channel parameters but on the following channel as well. Adaptation can help to stop the sudden death of entanglement in situations where the distillation procedure is insufficient. It is rather complex problem to find generally optimal adaptation. We rather give some simple but still valuable examples of quantum channels which can be adapted by our method. In the first example we show that for some cases of channels there exists unitary transform between the channels which can undone the sudden death of entanglement and we even show that this unitary operation can be applied on the input entangled state. This means that no entanglement breaking really occurs. If there is really entanglement breaking we call it non-trivial feature of sudden death of entanglement which means that we cannot undone the sudden death before and after the composite channel. In the second example we give proper example of the quantum channel (concatenation of depolarization and amplitude damping channels) adaptation by quantum filters.

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QUANTUM ESTIMATION OF NON-OBSERVABLE QUANTITIES

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Several quantities of interest in quantum information are nonlinear functions of the density matrix and cannot, even in principle, correspond to proper quantum observables. Any method aimed to determine the value of these quantities should resort to indirect measurements and thus corresponds to a parameter estimation problem whose solution, i.e the determination of the most precise estimator, unavoidably involves an optimization procedure. We review local quantum estimation theory and apply it to two different non-observable quantities: entanglement and phase-shift. As concern entanglement estimation, we evaluate quantum Fisher information for discrete and continuous variable systems and for different entanglement measures. Our results indicate that entanglement may be efficiently estimated when it is large, while the estimation of weakly entangled states is, in most cases, an inherently inefficient procedure. As concern phase estimation, we address both qubit and continuous variable Gaussian states and evaluate the quantum Fisher information for families of pure states undergoing a phase-diffusion master equation. We derive the optimal probe states and quantify how noise degrades the estimation efficiency. We also compare the ultimate quantum limit with the precision achievable with feasible measurements.

QUANTUM CHERNOFF BOUND AS A MEASURE OF POLARIZATION FOR A QUANTIZED FIELD

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The degree of polarization of an arbitrary quantum state ρ describing a transverse electromagnetic field can be defined as the distance between ρ and the set of all quantum unpolarized states. Two metrics have been considered for evaluating the degree of polarization, namely the Hilbert-Schmidt and the Bures metric [1].

We propose a new definition for the degree of polarization in terms of the quantum Chernoff bound. The recently discovered quantum Chernoff bound has previously been used to introduce a measure of nonclassicality for one-mode Gaussian states [2].

We apply the new definition to compute the degree of polarization of some particular quantized field states.

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NUCLEAR QUANTUM OPTICS: QED THEORY OF LASER-ATOM AND LASER-NUCLEUS INTERACTION AND DYNAMICS WITH INTENSE LASER PULSES

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QED theory is developed for studying interaction of atoms and nuclei with an intense and superintense laser field. Method bases on a description of system in the field by the k-photon emission and absorption lines. The lines are described by their QED moments of different orders, which are calculated within Gell-Mann & Low adiabatic formalism [1,2]. The analogous S-matrix approach is developed for consistent description of the laser-nucleus interaction. We have studied the cases of single-, multi-mode, coherent, stochastic laser pulse shape. Results of the calculation for the multi-photon resonance and ionization profile in Cs, Yb, Gd atoms are presented. It is also studied the phenomenon of the above threshold ionization. Efficiency of method is demonstrated by QED perturbation theory calculations for the two-photon ionization cross-sections for extended photon energy range (including above-threshold ionization) in Mg. Comparison with the R-matrix calculation of Luc-Koenig et al is given. Strong field (DC, AC) Stark effect for nuclei, atoms, including Rydberg atoms, is studied within new quantum approach, based on the operator PT [1]. We present here the calculation results of the Stark resonances energies and widths for a number of atoms (H, Li, Tm,U etc.) and for a whole number of low-lying and also Rydberg states. We discovered and analyzed the weak field effect of drastic broadening of widths of the Letokhov-Ivanov re-orientation decay autoionization resonances in Gd, Tm, U atoms and the corresponding nuclei.

Atomic dynamics with the rectangular and non-rectangular laser pulses is studied and the results of numerical calculation of population kinetics of the resonant levels for atoms in the non-rectangular pulse field on the basis of the modified Bloch equations are presented. The equations describe an interaction between two-level atoms ensemble and resonant radiation with an account of the atomic dipole-dipole interaction. A new idea of this work is discovery of strengthen possibility of manifestation for the internal optical bi-stability effect special features in the temporary dynamics of populations for the atomic resonant levels under adiabatic slow changing the field intensity. Modelling nuclear ensembles in a super strong laser field provides opening the field of nuclear quantum optics.

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EFFECTIVE MASS OF PHOTONS AND HEAVY PHOTONS EXISTANCE IN PHOTONIC CRYSTALS

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Photons in photonic crystals are some type of quasiparticles as electrons, phonons, polaritons and others. Accordingly we can determine effective mass of photons if energy from impulse dependencies or dispersion laws for photonic branches are known. By using some phenomenological model we have obtained photonic branches dispersion law in analytical manner and have calculated effective masses of photons for the first, second and third photonic branches of photonic crystals. It is known from lattice dynamics theory that in real crystals local modes in forbidden gap may exist due to some defects, imperfections or strong phonon-phonon coupling. The group velocity of corresponding waves is very small and effective mass of corresponding quasiparticles (heavy, localized phonons) is very large. In photonic crystals there are also forbidden gaps or so called "stop-bands" for some crystalline directions. If in globular photonic crystals [1,2] defects or inclusions are present as a result of some substances or quantum dots embedding into the pores between the globules of photonic crystals, some local electromagnetic states, corresponding to heavy, localized photons, inside forbidden gap should appear. Similar effect is predicted for photonic crystals due to strong interactions of photons with vibration excitations of globules — "globnons".

Experimental results are presented for opals matrices, consisting from quartz globules, having fixed diameter (200-300 nm) and forming cubic face centred lattice. Between globules there were pores (size: 50-70 nm), filled by some organic or inorganic substances and, in some cases, semiconductor or conductor quantum dots. We have recorded transmission and reflection spectra of investigated photonic crystals and have obtained parameters of stop band in visible range, corresponding to gap between the first and second photonic branches. For reflection experiments at small intensity of exciting light sources (halogen lamp or white light diode) the shape of reflectance spectrum was smooth in accordance with the simplest theory of light reflection from photonic crystal surface. With increase of exciting light intensity and for ultraviolet source of light we have observed additional peak inside stop-band, identified as heavy photon. At low temperature of globular photonic crystal the existence of light emission, corresponding to heavy photons, have been observed during several seconds after exciting source of light (impulsive laser) switching out. Some applications of heavy photon light emission, connected with nonlinear optics phenomena, Raman light scattering and new type lasing effect, are discussed.

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NON-MARKOVIAN DYNAMICS OF A DRIVEN TWO-STATE SYSTEM

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In quantum optics the precise description of the interaction between atoms and light is of fundamental importance. The theory of open quantum systems addresses the question of decoherence, a phenomenon that arises from the interaction between a system and its environment, e.g. the electromagnetic field surrounding the atoms. In particular, if the environment is structured, the short time-scale dynamics of the system exhibits an interesting non-Markovian behavior due to the exchange of information between the system and the environment.

In this work we consider a two-state system driven by a near-resonant laser in a structured reservoir modelled by infinitely many quantum harmonic oscillators. The dynamics of the two-level system is studied to second order in perturbation theory. The aim is to refine the description of the dynamics in such way to include the first non-Markovian corrections.

The transition from the Markovian description to the non-Markovian one produces richer dynamics, whose physical meaning can be studied by means of Non-Markovian Quantum Jumps method [1]. Our study reveals how the non-Markovian effects are connected to the particular structure of the reservoir and generally we shed light on how driven two-state systems behave in structured reservoirs.

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ENTANGLEMENT SWAPPING WITH BELL MEASUREMENT IN QUANTUM MEMORIES

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Unlike in a beam-splitter interference, a principal advantage of quantum memory [1] should be no necessity of time-synchronization between several states arriving to the memory. All the states coming at random times within a storage time of memory could exhibit, in principle, a perfect overlap with a stored quantum state. This principle was suggested in coherent-state purification where an information in many noisy copies is concentrated to a single copy preserving mean values simultaneously with a minimization of the excess noise [2].

In our contribution we analyze novel possibility of entanglement swapping using Bell measurement based on quantum memory. Two light pulses coming from two distant quantum memories, where entanglement between light and atomic modes is established, pass through further quantum memory at random times (within a storage time of memory). After the interaction and measurement of passed beams through memory, another auxiliary probe pulse is sent into memory. Now, after measurement of probe pulse, the proper feed-forward displacements of atomic states in distant memories are done. Although this Bell measurement is unperfect, due to vacuum probe pulse and vacuum atomic state in memory, the entanglement swapping is achieved. It will be shown that amount of entanglement increases with the gain of quantum memory. Maximization of entanglement with respect to gains of feed-forward apparatus and protocol with several memories are also discussed.

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A CLASS OF QUANTUM GATE ENTANGLER

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Entangled states are very important resource in quantum information processing. In general, a quantum computer is build using quantum circuit containing wires and elementary quantum gates. For an entangled based implementation of the quantum computer one also needs to construct quantum gates entanglers. It is also important that these quantum gates entanglers are able to produce any desire class of multipartite entangled quantum states.

We will construct quantum gates entanglers for different classes of multipartite states based on the definition of W and GHZ concurrence classes. We will review the basic construction of concurrence classes based on orthogonal complement of positive operator valued measure (POVM) on quantum phase. Next, we will construct quantum gates entanglers for different classes of multi-qubit states. We will show that these operators can entangle multipartite state if they satisfy some conditions for W and GHZ classes of states. Finally, we explicitly give the W class and GHZ classes of quantum gates entanglers for some multi-qubit states.

SELECTIVE EXCITATION OF MULTIPLE STATES IN ATOMIC SODIUM BY A SINGLE CHIRPED FEMTOSECOND LASER PULSE

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In this paper we demonstrate experimentally and theoretically that a single chirped femtosecond laser pulse can be used to selectively populate the highly excited levels $5p$, $6p$ and $7p$ in a sodium atom. These include population predominantly of a single level or a coherent superposition of two, or even all three, of them. The population distribution is controlled by the frequency domain chirp parameter (or chirp) only, without the necessity of sophisticated pulse shaping. The paper extends two earlier techniques in several significant directions. The technique of Melinger et al [1] uses a single chirped picosecond laser pulse to selectively excite the two fine-structure sublevels $3p_{1/2}$ and $3p_{3/2}$ in sodium. The present technique adds a dynamic Stark shift to the control tools, which enables the population of a third state, and also the creation of superpositions of states. The technique of Clow et al [2] uses a shaped femtosecond pulse to selectively populate a single highly excited level. The present technique is more flexible for it allows to populate several different levels by varying only the chirp parameter.

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SYMMETRY, ENTANGLEMENT AND COHERENT DEPOLARIZATION IN QUANTUM POLARIZATION OPTICS

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We discuss the role of the local and global polarization $SU(2)$ symmetries of quantum light fields in characterizing both quantitative and qualitative aspects of entanglement in polarization quantum optics [1-3]. The use of the global polarization $SU(2)_{gl}$ symmetry is shown to specify a (kinematic) sort of entanglement for polarization states of multi-mode radiation. The appropriate entangled states are determined as eigenvectors of two commuting operators of the total polarization (P) quasispin generating special collective polarization bases in the spaces of quantum states of multi-mode radiation. The "entangled nature" of these states is elucidated in their formal construction containing, besides photon creation operators $\hat{a}^\dagger_{-j}$, some composed (biphoton) operators

$$\hat{Y}^\dagger_{ij} = \frac{1}{2}[\hat{a}^\dagger_i \hat{a}^\dagger_{-j} + \hat{a}^\dagger_{-i}\hat{a}^\dagger_{+j}], \quad \hat{X}^\dagger_{ij} = \frac{1}{2}[\hat{a}^\dagger_{+i}\hat{a}^\dagger_{-j} - \hat{a}^\dagger_{-i}\hat{a}^\dagger_{+j}] \tag{1}$$

satisfying the equations $[\hat{Y}^\dagger_{ij}, \hat{P}_3] = 0, \quad [\hat{X}^\dagger_{ij}, \hat{P}_{a=1,2,3}] = 0\,(\hat{P}_{a=1,2,3}$ are components of the total P- quasispin). Actions of any combinations of the operators $\hat{Y}^\dagger_{ij}, \hat{X}^\dagger_{ij}$ on the vacuum vector generate in the general case unusual (coherent) states of unpolarized light [1,2] and , in particular, two "diagonal" Bell states $|\Phi_0\rangle = \sqrt{2}\,\hat{Y}^\dagger_{12}|0\rangle$, $|\Psi_0\rangle = \sqrt{2}\,\hat{X}^\dagger_{12}|0\rangle$. Two other Bell states $|\Phi_\pm\rangle$ can be got by the global $SU(2)_{gl}$ transformations : $|\Phi_+\rangle = \hat{U}(\mathbf{w}_+ = (0, \pi/2, 0))\,|\Phi_0\rangle$, $|\Phi_-\rangle = -i\hat{U}(\mathbf{w}_- = (\pi/2, 0, 0))\,|\Phi_0\rangle$, $\hat{U}(\mathbf{w}) \in SU(2)_{gl}$ which are associated with another (dynamic) sort of entanglement in polarization quantum optics. In general cases dynamic entanglement is due to both global and local $SU(2)$ symmetries of the Hamiltonians of the matter-radiation interaction. We also define some new entanglement measures which have an operational meaning related to characteristics of light depolarization. In particular, for one-biphoton states we find a simple relation

$$C^2 = 1 - \frac{1}{2}[\mathcal{P}_1^2 + \mathcal{P}_2^2]$$

between the Wooters concurrence C [4] and partial degrees of polarization $\mathcal{P}_{i=1,2}$ of two spatiotemporal modes [5]. Results obtained were used to analyze entangled states produced in spontaneous parametric scattering processes in multiply domained KH2PO4 crystals [5].

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ON TREATING ATOMIC PARITY NONCONSERVATION IN HEAVY ATOMS AND OBSERVING P AND PT VIOLATION USING NMR SHIFT IN A LASER BEAM: TO PRECISE THEORY

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During the past decade, first of all the optical experiments to detect atomic parity onconservation (PNC) have progressed to the point where PNC amplitudes can be measured with accuracy on the level of a few percents in certain heavy atoms [1]. Promising idea (Forston) is to apply the techniques of laser cooling and ion trapping to measurement of the PNC in $6s^2S_{1/2}$-$5d^2D_{3/2}$ transition of the singly ionized barium. To provide an adequate treating these experiments in terms of the standard model for a electro-weak interaction, comparison of the measured amplitudes with theoretically defined ones is required. Nowdays the PNC in atomic systems has a potential to probe a new physics beyond the standard model. In our paper we systematically apply the formalism of the QED many-body perturbation theory [2] to precise studying PNC effect in heavy atoms with account for the relativistic, nuclear and radiation QED corrections. Earlier an efficiency of this approach has been demonstrated in the precise calculation of the hyperfine structure constants, E1, M1 transition probabilities for heavy atoms and heavy ions [3]. We present the preliminary calculation results for energy levels, hyperfine structure intervals, E1-,M1-transitions amplitudes in heavy atoms of ^{133}Cs, ^{137}Ba$^+$, ^{207}Pb, ^{119}Sn. As example, let us present below the calculation result for the parity non-conserving 6s-7p dipole amplitude in Cs. Our calculation gives the value: D=<6s|Dz|7s>=-0.903×10^{-11} i|e|a(-Q_w/N). For comparison let us present other known results (c.f.[1]): D=-0.91×10^{-11} i|e|a(-Q_w/N) by Dzuba etal (Novosibirsk); D=-0.908×10^{-11} i|e|a(-Q_w/N) by Bouchiat etal (Paris); D=-0.935×10^{-11} i|e|a(-Q_w/N) by Johnson etal (Indiana), D=-0.902×10^{-11} i|e|a(-Q_w/N) and D=-0.905×10^{-11} i|e|a(-Q_w/N) by Johnson-Sapirstein-Blundell (Notre Dame). Comparison of calculated D value with the measurement by Noeker et al gives the following data of weak nuclear charge Q_w and the Weinberg angle ϑ_W. We also discuss a new improved possibility for observing P and PT violation using a nuclear magnetic resonance (NMR) frequency shift in a laser beam [4]. The cited shift is provided by a correlation of the a nuclear spin with the momentum of the photon ($\mathbf{Ik}$).

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INDUCED INTERACTIONS FOR ULTRA-COLD FERMI GASES IN OPTICAL LATTICES

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The optical tools for the realization of ultra-cold gases provide a novel opportunity to directly study quantum many-body phenomena in highly controllable environments. Particularly, in optical lattices, the behavior of interacting fermionic atoms indicates that the area of conventionally condensed matter theories needs to be further expanded. Here we focus on fermionic superfluidity in this artificially adjustable lattice system, which is still in need of full characterization despite the evidence of its existence in optical lattices that has been observed very recently.

We investigate the effect of optical lattice potentials on the onset of superfluidity by using the Gorkov-Melik-Barkhudarov (GMB) correction to the BCS mean-field theory for two-component Fermi gases [1]. We calculate the superfluid order parameter in three and two dimensional lattices with various settings including the crossover from three to one dimension. We find that the strong suppression of the order parameter is induced by the lattice effects. The predictions on the order parameter through the GMB corrections are in qualitative and, for the cases studied, in quantitative agreement with previous quantum Monte Carlo results in the attractive Hubbard model. We discuss how the GMB correction extends the validity of the mean-field theory to a wider range of tunable optical lattice systems in different dimensions.

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PREPARATION OF EVEN AND ODD OPTICAL SCHRÖDINGER CAT STATES

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Superpositions of two coherent states are often referred to as Schrödinger cat states due to their resemblance of superposing macrosopic, distinguishable objects. Preparation of such superpositions for traveling wave optical fields is an experimentally demanding task, although there are a number of proposals and some experiments (see e.g. [1] and references therein). We propose a scheme based on Gerry's cross Kerr medium scheme [2] complemented by conditional homodyne measurement. In this way even and odd cat states become available.

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DYNAMICS OF THE LASER COOLED AND TRAPPED RADIATOR INTERACTING WITH THE SINGLE-MODE CAVITY FIELD

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We study the interaction between the equidistant three-level laser cooled and trapped atom (ion) and the single-mode cavity field. The dipole moment matrix transition elements between the adjacent atomic energy levels are supposed to be different. This problem generalizes the model of the pair of cold two-level atoms interacting with the squeezed vacuum [1].

We assume that the three-level radiator is laser cooled into the state with zero-point vibrational energy with the vibronic quantum number $\langle n_v \rangle = 0$. For example, the two-stage laser cooling experiment of the $^{198}Hg^{+}$ ion was demonstrated [2], in which Diedrich et al achieved $\langle n_v \rangle \simeq 0$ by optical sideband cooling with the temperature $T \simeq 50\mu K$.

The exact analytical solution for the atom-field state-vector is found with the help of the Schrodinger equation in the case, in which at the initial moment the three-level radiator is supposed to be in the first excited state. By using this solution the quantum-statistical and squeezing features of the single-mode cavity field are investigated. We obtained the exact analytical expressions for the mean photon number, their fluctuations and the atomic population inversion. It is found that the single-mode cavity field statistics has the tendency towards oscillations. It should be noted that for certain values of the initial mean photon number takes place the Sub-Poissonian photon statistics. Much attention is also devoted to the squeezing properties of the radiation field. The obtained results are compared with those for the single two-level atom model [3]. It is found that in the equidistant three-level model the exact periodicity of the squeezing revivals is violated by the analogy with the single two-level atom one.

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DENSITY RESPONSE OF A TRAPPED SUPERFLUID FERMI GAS BEYOND THE LOCAL DENSITY APPROXIMATION

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We study the density response of a trapped superfluid Fermi gas. Working in the Bogoliubov-deGennes formulation, we can go beyond the local density approximation. Furthermore, our approach is applicable also to imbalanced gases with different atom numbers in the two (hyperfine) spin states, opening an interesting possibility of studying the density response of an Fulde-Ferrel-Larkin-Ovchinnikov-type spin-polarized superfluid.

PHASE EFFECTS ON THE ENTANGLEMENT AND DISENTANGLEMENT FOR KERR-LIKE COUPLER

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It is known that nonlinear systems can be used for generation of maximally entangled states [1]. The problem of preservation of the entanglement obtained in this way seems to be particularly important, especially in the context of quantum information theory.

We analyse the entanglement dynamics in nonlinear coupler interacting with external environment (for description of nonlinear optics models see for instance [2]). The model discussed is assumed to loose its energy by the interaction with external thermal bath. For such a system we have found that the entanglement creation and its vanishing strongly depend on the phase of the coupling constants describing the interactions within the coupler.

To investigate these phenomena the density matrix approach is applied with the master equation formalism, allowing the simulation of the damped system dynamics.

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ABOVE-BARRIER REFLECTION OF ULTRA-COLD ALKALI ATOMS BY RESONANT LASER LIGHT WITHIN THE GROSS-PITAEVSKII APPROXIMATION

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Above-barrier reflection of ultra-cold atoms of alkali gases by resonant laser light has been considered analytically using the Gross-Pitaevskii approximation. The reflection coefficient has been derived taking into account a weak nonlinearity of the Schrödinger equation produced by the interaction between cold alkali atoms. Thus, we solved analytically the one-dimensional stationary Gross-Pitaevskii equation

$$-\frac{1}{2}\frac{d\psi}{dx^2}+V(x)\psi+\alpha|\psi|^2\psi=E\psi$$

Here $E > 0$ is the kinetic energy of the cold atom, $V(x) = 0$ at $x < 0$ and $V(x) = V$ at $x > 0$. The quantity α is the small nonlinearity parameter which is proportional to s-wave scattering amplitude. Atomic units are used, $\hbar = M = 1$ (M is the mass of the atom). Nonlinear term is given in Hartree approximation for short-range interaction between atoms. The potential $V(x)$ approximates the absorption of laser photons by cold alkali atoms, when π-laser pulse propagates opposite to the initial atomic motion [1].

The analytical solution was obtained for the reflection coefficient by the method of many scales in order to remove secular terms. This solution contains the first order perturbation term with respect to the small nonlinearity parameter α. The conclusion has been made that repulsive nonlinearity ($\alpha > 0$) increases the above-barrier reflection while the attractive nonlinearity ($\alpha < 0$) decreases the reflection coefficient. Both incident and reflected waves are distorted by the nonlinearity in comparison to the well known plane waves without any nonlinearity.

We considered also the case when the laser pulse propagates in the same direction as a cold atom. It was shown that the role of nonlinearity in this case is much weaker. It was shown that the role of nonlinearity becomes stronger when the kinetic energy of an atom is nearly to the height of the quantum potential rectangular barrier $V(x)$. When the atomic kinetic energy E is equal to the barrier height V, the transmission coefficient is nonzero in the case of the attractive nonlinearity. However, in the case of repulsive nonlinearity the transmission coefficient is nonzero only at some value of $E > V$. It was shown also that Bose-Einstein condensate is absent in the considered rectangular potential, unlike the case of the trapped potentials [2], or the case of reflection by solid surface [3].

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ENTANGLEMENT OF QUBITS THROUGH A JOINT DETECTION OF PHOTONS

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We consider a model of two remotely located stationary qubits (atoms, superconducting charge and flux qubits, spins in quantum dots) each independently coupled to a single mode electromagnetic field. The interference of the electromagnetic field modes and their coincidence measurement ensures qubits entanglement. We present analytical formulas for the linear entropy and the density matrix (which can be measured in quantum tomography experiments) for the entangled qubits and discuss their dependence on the initial state and the detection time. The created entanglement survives in the presence of dissipation with realistic decoherence times. This scheme may be used for scalable quantum computation and quantum communication.

NON-MARKOVIAN DYNAMICS OF THE SPIN-BOSON MODEL

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The spin-boson model is widely studied, mostly because of its many applications in the field of quantum information theory, quantum optics, solid state physics and chemistry. The model can describes e.g. two-well potential [1], double quantum dots [2] and different biomolecular systems [3]. Because the spin-boson model is not exactly solvable many different types of approximations are commonly used for studying the dynamics of the spin system. Especially, it is often assumed that the system is Markovian.

The Markovian description of the system gives a coarse-grained version of the dynamics but fails to represents the non-Markovian memory effects present in short time scales. Understanding the details of the short time dynamics is crucial e.g. for the description of solid state qubits and thus a non-Markovian theory of the spin-boson model is highly desirable.

We have derived a time-convolutionless form of the non-Markovian second order master equation describing the spin dynamics. This simple form enables one to use the non-Markovian quantum jump method (NMQJ) [4] in order to unravel the dynamics of the system. The NMQJ-method may give new physical insight to the non-Markovian character of the spin-boson model.

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Interference contrast in multi-source few photon optics. Part 1

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Optical setups are an important implementation of various quantum information tasks, e.g. quantum teleportation [1], entanglement swapping [2] or quantum repeaters [3]. Most of the modern quantum optical experiments rely on parametric down-conversion (PDC). It is a highly unlikely process in a non-linear crystal, in which a photon from the pumping beam changes into two highly correlated photons in the output modes. Recent years have brought a significant progress in realizing multisource PDC experiments allowing multiphoton interference [4,5]. It is important to check if there are any fundamental obstacles for conducting future multiphoton interference experiments. Such obstacles might make some involved quantum information protocols impossible to be realized via purely photonic techniques.

Visibility (interferometric contrast) in multiphoton PDC experiments is impaired by the statistical properties of the emission process [6]. Therefore, a quantitative analysis of the influence of these factors is important if we want to use the non-classical properties of light in quantum communication. E.g., in order to show a conflict between quantum mechanics and classical description, the visibility should be greater than some critical value V^{crit}.

The aim of this work is to calculate the maximal possible visibility due to the production of the additional pairs of photons, which occurs in the strong pumping regime. We also analyze the properties of the effective output state in PDC process.

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DRIVEN ENTANGLEMENT FROM AN ATOM COUPLED TO A RESERVOIR

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We study a single two-level atom interacting with a reservoir of modes defined by its spectral function. Considering exactly solvable models, we try to quantify and examine the properties of entanglement between different parts of the reservoir (both with and without the atom). Our analysis makes use of different measures of entanglement, such as the concurrence vector and the generalised entanglement. The system evolution is determined both analytically, for certain limits, and numerically, in the framework of a discrete bath. From our analysis, we were able to derive entanglement properties between the atom and the modes, and also between the reservoir modes.

CONDITIONAL PREPARATION OF ARBITRARY SUPERPOSITIONS OF ATOMIC DICKE STATES

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We propose an experimentally accessible procedure for conditional preparation of highly non-classical states of collective spin of an atomic ensemble. The quantum state engineering is based on a combination of QND interaction between atoms and light previously prepared in a non-Gaussian state using photon subtraction from squeezed vacuum beam, homodyne detection on the output light beam, and a coherent displacement of atomic state. The procedure is capable of non-deterministic preparation of a wide class of superpositions of atomic Dicke states. We present several techniques to optimize the performance of the protocol and maximize the trade-off between fidelity of prepared state and success probability of the scheme.

FINITE TIME DISENTANGLEMENT IN NONLINEAR COUPLER SYSTEM

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We deal with the model of Kerr coupler described in [1] that can be treated as qubit-qutrit system. We focus on the dynamics of the initially generated maximally entangled state (MES) evolving under the influence of external thermal bath, using the density matrix approach.

The degree of the entanglement can be described by various parameters. In this communication we concentrate on the concurrence $C(t)$ defined for the two qubit systems by Wooters [2]

$$C(t) = max\left(\sqrt{\lambda_1} - \sqrt{\lambda_2} - \sqrt{\lambda_3} - \sqrt{\lambda_4},\, 0\right) \quad , \tag{1}$$

where the parameters λ_i are the eigenvalues of matrix constructed from the density matrix $\hat{\rho}$, obtained directly from the master equation. While for the two-qubit system the definition of the concurrence can be applied straightforwardly, for a qubit-qutrit system there is a need to extract from the system's density matrix a matrix for a two-qubit system using a projection operator according to [3].

For such a model, we discuss the processes of sudden disentanglement and the possible reappearance of the entanglement in the system whose parameters are set to vary.

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TRANSMITTIVITY IN THE PRESENCE OF NOISE AND ENTANGLEMENT

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We consider an electron magnetically interacting with a spin-1/2 impurity, embedded in an external environment whose noisy term acts only on the impurity's spin, and we find expressions for the electron transmission and reflection probabilities in terms of the phenomenological noise parameters. Further, we consider an electron magnetically interacting with two spin-1/2 impurities and investigate the effects of entanglement and noise on the transmission properties of the system.

ULTRACOLD FERMIONS IN OPTICAL LATTICES. DYNAMICAL ANALYSIS OF THE MOTT INSULATOR PHASE

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Motivated by the recent experimental results on the Mott insulator phase of fermionic atoms in optical lattices [1], we investigate the response to a periodic lattice modulation of a cloud of fermionic atoms loaded in a 1D lattice. To that end, the system is modeled in terms of a repulsive Hubbard Hamiltonian, with time-dependent hopping amplitude.

In particular we focus on the time evolution of the double occupancy, defined as the fraction of sites filled by two atoms, as a function of the modulation frequency. We relate the dynamical-response properties of the double occupancy, to the spin properties of the system, suggesting hence a possible tool to detect an antiferromagnetic phase in fermionic lattice systems.

In this work a time-evolving block decimation (TEBD) algorithm is considered for the calculation of both ground and time-evolved states, allowing thus the exact evaluation of relevant properties of the system.

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SUDDEN DEATH AND SUDDEN BIRTH OF ENTANGLEMENT IN COMMON STRUCTURED RESERVOIRS

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Entanglement is one of the most intriguing features of quantum mechanics. Not only it is of absolute relevance to the foundations of quantum theory but it represents a key resource for a number of application of modern physics. Quantum properties, however, are very fragile. Realistic quantum systems are not closed, and due to the interaction with the environment their entanglement and coherence can be irretrievably lost. Anyway, recent works, have shown that entanglement can actually revive or be preserved using the quantum Zeno effect [1], or it can even be trapped [2]. Such effects arise when the system of interest interacts with non-Markovian reservoirs.

We study the exact entanglement dynamics of two qubits in a common structured reservoir [3]. We present interesting features of the two qubits-entanglement dynamics as the resurrection of entanglement after a period of death, or the revival of disentanglement after entanglement has been suddenly created. These peculiar characteristics of entanglement dynamics are due to two combined effects: the non-Markovian back-action of the reservoir and the reservoir-mediated interaction between the qubits.

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EXPERIMENTAL REALIZATION OF PROGRAMMABLE QUANTUM GATE

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We experimentally demonstrate a programmable single-qubit quantum gate. This device applies a unitary phase shift operation to a data qubit with the value of the phase shift being fully determined by the state of a program qubit. Note that an exact specification of the phase shift would require infinitely many classical bits. This is a striking feature of demonstrated programmable quantum gate because information on phase shift is faithfully encoded into a single quantum bit. The theoretical success probability of the protocol for our experimental realization is 25%. Our linear optical implementation is based on the encoding of qubits into polarization states of single photons, two-poton interference on a polarizing beam splitter, and measurement on the output program qubit.

We characterize the programmable gate by full quantum process tomography. The achieved average quantum process fidelity is 97.1%. According to simple theoretical model the achievable average process fidelity is 97.7%, taking into account imperfections of the polarizing beam splitter. Moreover, using a different set of program states the device can operate as a programmable partial polarization filter with attained fidelity over 97%.

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NONLINEAR HARMONIC BOSON OSCILLATOR

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We consider the Hamiltonian which characterizes a boson, such as

$$H = \frac{1}{2m}\, p^2 + \frac{m\omega^2}{2}\, q^2 + \beta q^4 \ , \tag{1}$$

where p and q represent the generalized impulse and coordinate respectively, while the term βq^4 stands for the anharmonical part with β the anharmonicity coefficient. The annihilation and creation operators are described as $a = \frac{1}{\sqrt{2m\hbar\omega}}\,(m\omega q + ip)$ and $a^\dagger = \frac{1}{\sqrt{2m\hbar\omega}}\,(m\omega q - ip)$ respectively. Then, Eq. (1) becomes

$$H = \hbar\omega a^\dagger a + \frac{1}{2}\hbar\omega + \beta' \left(a + a^\dagger\right)^4 ,\ \beta' = \beta\left(\frac{\hbar}{2m\omega}\right)^2 . \tag{2}$$

We will denote by $\bar{H} = \langle\alpha|H|\alpha\rangle = \left\langle 0\middle|D^\dagger(\alpha)\, H D(\alpha)\middle|0\right\rangle$, where $|\alpha\rangle = D(\alpha)\,|0\rangle$ is a coherent state, $D(\alpha) = \exp\left(\alpha a^\dagger - \alpha^* a\right) = e^{-\frac{1}{2}\alpha\alpha^*} e^{\alpha a^\dagger} e^{-\alpha^* a}$ is the displacement operator, and $|0\rangle$ is the electromagnetic field vacuum state [1,2]. We shall assume $H = f\left(a, a^\dagger\right)$. By denoting $X = a + a^\dagger$, we also have $\langle\alpha|X^n|\alpha\rangle = \bar{X}^n$ and after some calculi we obtain the new expression of $\bar{H}$:

$$\bar{H} = \hbar\omega\alpha\alpha^* + \frac{\hbar\omega}{2} + \beta' \left[(\alpha+\alpha^*)^4 + 6\,(\alpha+\alpha^*)^2 + 3\right] \tag{3}$$

The Hamilton equations given by $i\dot{\alpha} = \frac{\partial H}{\partial \alpha^*}$ can be expressed as

$$\left\{ \begin{array}{l} i\dot{\alpha} = \hbar\omega\alpha + \beta'\left[4\,(\alpha+\alpha^*)^3 + 12\,(\alpha+\alpha^*)\right] \\ -i\dot{\alpha}^* = \hbar\omega\alpha^* + \beta'\left[4\,(\alpha+\alpha^*)^3 + 12\,(\alpha+\alpha^*)\right] \end{array} \right. , \tag{4}$$

where $2Q = \alpha + \alpha^*$ and $T = \left[4\,(\alpha+\alpha^*)^3 + 12\,(\alpha+\alpha^*)\right]$. We finally have

$$Q" + \omega^2 Q + \frac{\hbar^2}{m\omega}\beta\left(8Q^3 + 6Q\right) = 0 \ , \tag{5}$$

which will be shown to represent the equation of the classical perturbed oscillator. These states of motion can be achieved in case of trapped and laser cooled ions, confined both in linear and nonlinear electromagnetic traps.

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STABILITY ANALYSIS OF THE DYNAMICS IN A NONLINEAR ION TRAP

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Quadrupole ion traps have proven to be an extremely versatile tool in atomic physics, high-precision spectroscopy, fundamental tests on quantum mechanics theories, quantum metrology, physics of quantum information, studies of chaos and integrability, mass spectrometry, quantum optics and studies of non-neutral plasmas [1-3]. Ideal traps exhibit a pure quadrupole potential which leads to a harmonic binding force to the trap center. The finite size and unavoidable geometrical imperfections of the trap electrodes, misalignments and space charge in the case of several trapped ions add higher order (hexapole, octopole, etc.) contributions to the trap potential. This yields to strong instability in ion motion under otherwise stable trapping conditions. We examine the case of an ion confined in a quadrupole nonlinear Paul trap, which we will treat as a time-periodic differential dynamical system. In such case, the equation of motion along the x direction, for a particle of electrical charge Q and mass M, which undergoes interaction with a laser field in a quartic potential $V(u) = \mu u^4,\ \mu > 0$ and in presence of damping, can be expressed as

$$\frac{d^2u}{d\tau^2} + \gamma\frac{du}{d\tau} + [a - 2q\cos(2\tau)]\,u + \mu u^3 + \alpha\sin u = F\cos\omega_0 t\ , \tag{1}$$

where $u = kx$, $\tau = \Omega t/2$, $\alpha = 2k^2\Omega_0\cos\theta/M\Omega^2$, γ and μ are the damping and the anharmonicity coefficient respectively, while the adimensional parameters are expressed as $a = -16QU_0/M\Omega^2 d$ and $q = 8QV_0/M\Omega^2 d$, with $d = r_0^2 + 2z_0^2$. Ω stands for the micromotion frequency, U_0 and V_0 are the static and time-varying trapping voltages, r_0 and z_0 represent the trap semiaxes, while Ω_0 is the Rabi frequency for the ion-laser interaction and $\cos\theta$ is the expectation value of the x projection spin operator for the two level system with respect to a Bloch coherent state. The expression $F\cos\omega_0 t$ stands for the driving force, an external excitation at frequency ω_0.

In order to illustrate the dynamics of the trapped ion we will represent the trajectories in the phase space (phasic portraits) and extended phase space, with an aim to emphasize the existence of attractors for the ion motion. Due to anharmonicity, the frontiers of the stability diagram are shifted towards negative regions of the a axis in the plan of the control parameters (a, q).

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GENERATION OF A HYBRID CLUSTER STATE USING NON-DEMOLITION MEASUREMENTS

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It was recently shown [1] that special types of multipartite state, known as cluster states represent a resource for universal one-way computation, an expremely promissing type of quantum computing. Information can be written onto these clusters where it is processed and can then be read out via one-qubit measurements. This idea has been extended to include continuous variables (CV) with the advantage that CV states are simpler to generate and manipulate. Several schemes have been proposed for CV clusters involving four light modes [3], then more recently four atomic ensembles [4]. Here a scheme is proposed for the generation of a cluster state [1] of two atomic ensembles and two light modes, a so called hybrid cluster state. The quantum variables that correspond to position and momentum are the spin operators of the atoms, $\hat{J}_z$, $\hat{J}_y$ and the Stokes operators for the light $\hat{S}_z$,$\hat{S}_y$. Then for a linear cluster, we can rewrite the conditions for a cluster state as

$$\begin{aligned} &V(\hat{J}_{y1}-\hat{J}_{y2}) \to 0, \qquad V(\hat{J}_{y2}-\hat{J}_{z1}-\hat{S}_{z1}) \to 0 \\ &V(\hat{S}_{y2}-\hat{S}_{z1}) \to 0, \qquad V(\hat{S}_{y1}-\hat{J}_{z2}-\hat{S}_{z2}) \to 0 \end{aligned} \tag{1}$$

In our proposal a light mode, squeezed in the y polarization, is passed through each atomic ensemble. These interactions are governed by the QND-type Hamiltonian $H \propto S_z J_z$ which yields the equations of motion [2]:

$$\begin{aligned} \hat{S}'_y &= \hat{S}^{in}_y + \alpha \hat{J}^{in}_z, \qquad \hat{S}'_z = \hat{S}^{in}_z \\ \hat{J}'_y &= \hat{J}^{in}_y + \beta \hat{S}^{in}_z, \qquad \hat{J}'_z = \hat{J}^{in}_z \end{aligned} \tag{2}$$

As we can see, the atomic ensembles pick up information about the light fields. We then introduce 'entangling pulses', these also interact via QND Hamiltonians and so pick up information about both the light and atoms [2]. At the output, the entangling pulses are then measured to infer the spin (polarization) values of the atoms (light) in a non destructive way. This process is repeated on each atomic ensemble individually and on the light emerging from the atoms. The protocol generates the hybrid continuous variable cluster state. The atomic nodes open new possibilities for addressing and manipulating the hybrid cluster, whereas its implementation is simpler than that of the four-atom clusters.

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BERRY PHASE IN ATOM OPTICS

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The Berry phase is determined only by the parameter space topology and hence cannot be disturbed significantly by noise. It can be used to construct robust quantum gates. We suggest a scheme to observe the Berry phase using the atomic external degrees of freedom.

We consider two consecutive interactions of an atom with a near-resonant standing light waves. An atom is scattered by a standing wave, which is formed by two red-detuned traveling light waves, with wave vectors $\mathbf{k}_1$ and $\mathbf{k}_2$,

$$|\mathbf{k}_1| = |\mathbf{k}_2| = k,$$
$$\measuredangle(\mathbf{k}_1, \mathbf{k}_2) = 2\alpha.$$

Afterwards, the atom is scattered by a second standing wave, which is formed by two blue-detuned traveling light waves, with wave vectors $\mathbf{k}'_1$ and $\mathbf{k}'_2$,

$$|\mathbf{k}'_1| = |\mathbf{k}'_2| = k',$$
$$\measuredangle(\mathbf{k}'_1, \mathbf{k}'_2) = 2\alpha'.$$

We assume that both interactions turn-on and turn-off adiabatically. Within the rotating wave approximation and the adiabatic approximation on the atomic center-of-mass motion we obtain that the dynamical phase is cancelled out in the case of

$$k \cos\alpha = k' \cos\alpha'$$

and the final state of the atom differs from the initial state of the atom only by the Berry phase,

$$\gamma \propto \ln\left[1 + |V|^2/\Delta^2\right],$$

where Δ is detuning, V depends on the atomic internal and external degrees of freedom. Therefore, the scattering picture is determined by the atomic center-of-mass position.

NON-CLASSICAL PROPERTIES OF SQUEEZED KERR STATES

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Non-classical features (e. g., antibunching, sub-Poissonian photon statistics and squeezing) of light [1] found wide attention because of their potential applications not only in reduction of noise level in optical communication, in detection of the extremely weak gravitational radiation but in rapidly emerging quantum information processing [2]. With the development of techniques for making higher-order correlation measurements in quantum optics, interest naturally extended to the higher moments of the field also. Recently, Prakash & Mishra [3] found the general higher order inequalities involving expectation values of products of arbitrary powers of photon number and its fluctuation which exhibits non-classicality and studied higher-order sub-Poissonian photon statistics. Generation of states exhibiting higher order sub-Poissonian photon statistics in a physically realizable system, therefore, remain an open challenge.

To the best of my knowledge, study of higher-order squeezing and higher-order sub-Poissonian photon statistics for squeezed Kerr states [4] has not been done yet. Such fact motivates to investigate the possibility of higher-order sub-Poissonian photon statistics for squeezed Kerr states. We study higher order non-classical properties of squeezed Kerr states which is generated by squeezing the output of a Kerr medium whose input is coherent light. It is found that higher-order non-classical properties can coexist.

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IMPROVING CONTINUOUS–VARIABLE ENTANGLEMENT DISTRIBUTION BY SEPARABLE STATES

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Distribution of entanglement by separable states is a protocol in which two distant participants entangle their quantum systems by transmitting a third separable quantum system between their locations. The protocol was first proposed for qubits [1]. We extend the protocol into the domain of Gaussian states of infinitely-dimensional quantum systems [2], e.g., light modes. Next, we propose a new more simple and more efficient protocol distributing entanglement with six times higher logarithmic negativity than the original protocol [2]. This new protocol reveals that the distributed entanglement originates from the entanglement of sender's mode and the auxiliary mode used for distribution which is first destroyed by local correlated noises and restored subsequently by interference of the auxiliary mode with receiver's distant separable correlated mode.

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GEOMETRIC REPRESENTATION FOR THE STATES OF A QUANTUM REGISTER

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We present a geometric representation for the pure states of an n-qubit quantum register. We show that this representation can be used to classify and quantify the amount of entanglement contained by these states.

THE THRESHOLD CONDITIONS FOR FELWI .

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According to the main idea of Ref [1], a possibility of FELWI realization is strongly related to a deviation of electrons from their original direction of motion owing to interaction with the fields of undulator and co-propagating light wave. The deviation angle appears to be proportional to energy gained or lost by an electron during its passage through the undulator. Owing to this, the subsequent regrouping of electrons over angles provides regrouping over energies. In principle, a proper insallation of magnetic lenses and turning magnets after the first undulator in FELWI can be used in this case for making faster electrons running over a longer trajectory than the slower ones [2]. This is the negative dispersion condition, which is nesassary for getting amplification whithout inversion [3]. It's clear that the described mechanism can work only if the interaction-induced deviation of electrons (with a characteristic angle α) is lager than the natural angular width α_{beam} of the electron beam,

$$\alpha > \alpha_{beam} \tag{1}$$

As the energy gained/losed by electrons in the undulator and the deviation angle are proportional to the field strength amplitude of the light wave to be amplified, the condition (1) determines the threshold light intensity, only above which amplification without inversion can become possible. This threshold intensity is estimated below.

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A NEW MATHEMATICAL APPROACH FOR INVESTIGATION OF STATISTICAL PROPERTIES OF 1D DISORDERED QUANTUM N-PARTICLES SYSTEM IN EXTERNAL FIELD

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The investigation of $1D$ disordered quantum N-particles system (PS) under the influence of external field is conducted within the limits of the stochastic differential equation (SDE) of type Langevin-Schrödinger (L-Sch). Using L-Sch equation the $2D$ second order non-stationary partial differential equation is found, which describes the quantum distribution depending on energy of nonperturbed $1D$ quantum N-PS and on the external field's parameters. It is shown that the average value of interaction potential between $1D$ disordered quantum N-PS and on the external field, has the *ultraviolet divergence*. This problem is being solved by method of dimensional renormalization of the equation of quantum distribution function which is characteristic for the quantum field theory. By investigation of Helmholz free energy is found of conditions at which in the N-PS system occur the phase transitions of first order and in some areas of particles' chain are take place ordering.

In the work as well is investigated the problem of interaction of quantum system with stochastic environment in the result of which occurs self-organization of environment. The equation which describes the quantum distribution in the environment is received with using L-Sch type equation. In detail is investigated the case of interaction of regular $1D$ quantum N-PS with fundamental environment (with the electromagnetic component of quantum fluctuations). It is shown that the vacuum is quantized i.e in the vacuum the structure with defined sizes and topology is being formed which may be interpreted as a new quantum character for the particles system. It is shown that this character in contrast to de Broglie wavelength nonvanish at increasing of particles system mass, which says about existence of a new type of macroscopic quantum phenomena [1].

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THE SMITH PURCELL RADIATION

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A Smith-Purcell instability of relativistic electron beam in the absence of the resonator is considered within the framework of dispersion equation. We have found that zero-order approximation for solution of dispersion equation is the mirror case, when the electron beam propagates above plane metal surface (mirror). The condition of the Thompson or Raman regimes of excitation does not depend on beam current and depends on the height of the beam above grating surface.

MULTIPLY CONNECTED ROTATING SPIRAL STRUCTURES INSIDE WAVE-FRONT REVERSAL MIRRORS

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Phase singularities of optical beams attracted a substantial interest in recent decades from the point of view of optical information processing [1] and quantum information [2]. The optical nonlinearities had been shown to stimulate angular momentum transfer to ensemble of ultracold atoms [3] as a tool for light storage [4]. Less attention had been paid to phase-conjugation of optical vortices, although phase-conjugated (PC) replica of helical LG beam from BEC sample in nondegenerate four-wave mixing had been obtained quite recently. The origin of phase-conjugated photons from cold atoms had been interpreted as excitation of rotation inside BEC sample [3]. To our opinion the irrotation of the atomic cloud is a consequence of angular momentum conservation in PC mirror [5]. Consider for definiteness the interaction of the two counter-propagating paraxial laser beams inside Brillouin active medium. Let us choose classical counterpropagating optical fields and acoustic field. The linearly polarized pump field moves in positive direction of Z axis, the reflected Stockes field with the same polarization propagates in opposite direction. The acoustic field is excited via electrostrictive mechanism [6]. The conservation of angular momentum in wavefront reversal process is the cause of appearance of twisted rotating structures inside phase-conjugator [6]. The nontrivial topology of rotating multiply connected spatiotemporal pattern is shown to be the consequence of the perfect match of helical wavefronts[7]. The issues of fast [8,9] and slow light [3] in PC-mirrors are addressed.

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CONTEXTUALITY WITHIN QUANTUM MECHANICS USING 'PATH-SPIN' ENTANGLEMENT AND SUBENSEMBLE STATISTICS

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For a suitable Mach-Zehnder type setup that generates an 'intraparticle path-spin entanglement' for a spin-1/2 particle, a hitherto unnoticed quantum mechanical effect is demonstrated, viz. that at either of the two exit channels pertaining to a beam-splitter, the experimentally verifiable *subensemble mean value* of an arbitrary spin variable is contingent upon the choice of a comeasurable 'path' observable. Curiously, such an effect of 'context-dependence' occurs in a way so that for the *whole ensemble* comprising all the particles emerging through both the exit channels, the expectation value of any spin variable is ensured to be independent of the choice of the comeasurable 'path' observable. Interestingly, this effect, derived without taking any recourse to the notion of 'realism' or 'hidden variables', has no counterpart for the EPR-Bohm type 'interparticle entangled state' involving two spatially separated qubits, even though the mathematical form of the latter is the same as that of the path-spin 'intraparticle entangled state' considered here.

GENERALIZED NON-SIGNALING AND THE STRENGHT OF QUANTUM CORRELATIONS

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Quantum theory and relativity theory are well-established experimentally confirmed pillars of modern science. Yet, their peaceful coexistence is still not well understood. For example, the strength of quantum correlations between two particles is limited far below the degree allowed by the non-signaling principle. This principle forbids information gain about a distant system (sending signals) without transmission. Here we identify a generalized non-signaling condition stating that transmission of classical bits cannot lead to the information gain of more than it is contained in these bits, even if communicating parties share some correlations in advance. We prove this condition is satisfied in both classical and quantum physics and show that the quantum correlations are the strongest compatible with it. The generalized non-signaling is phrased in a theory-independent way and we suggest it is at the same fundamental level as the non-singling principle itself.

UNIQUE GEOMETRIC PHASE OF AN OPEN SYSTEM VIA TRAJECTORY APPROACH

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Unique unraveling of the Linblad master equation provided by the quantum state diffusion (QSD) theory is utilized to define a geometric phase of an open quantum system. It is then shown that such geometric phase is invariant on the general symmetry transformations of the Linblad equation. This natural property is not shared by the geometric phases based on other types of unraveling. The QSD geometric phase is computed for a qubit in dephasing and thermal environments.

RECYCLING OF QUANTUM INFORMATION

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It is well known that there exists an "information-disturbance" tradeoff between the quality of estimating a state of a quantum system and the degree the initial state has to be altered in the course of the estimation procedure carried by an observer. (A tight bound on the tradeoff has been derived by Banaszek [1] for single copy of a d-level system in a pure state in terms of estimation versus after-measurement state fidelities.) This means the after-measurement state can still carry partial information on the initial quantum state which can be estimated by further observer whose estimation procedure (in general) again introduces further disturbance and so on. Consequently, one can pose several questions related to the estimation fidelity of the kth observer under reasonable assumptions under which the answers to these questions are not trivial, which is what we do.

To be specific, we consider the following situation: a pure state of a d-dimensional system known to the preparer but unknown to the observers is encoded into a pure state (from a $SU(d)$-invariant family of states) of a D-dimensional system. The encoding is $SU(d)$-covariant. The preparer or any of the observers do not share a basis (nor a set of bases other than the whole set $\{U|0\rangle, U \in SU(d)\}$) nor do they possess or communicate any information that would reveal (or constrain the possible set of) their estimation results, not even probabilistically. Each observer uses estimation strategy saturating the tradeoff bound (i.e. introducing minimal disturbance given an information gain). We calculate the maximum average estimation fidelity for the kth observer if: i) each observer's strategy maximizes his estimation fidelity; ii) each of the observers' strategies maximize their estimation fidelities given the condition that all observers' fidelities have to be the same (each observer knows his order, k); iii) each of the observers' strategies maximize the fidelity of the last observer's estimation given the condition that all observers' strategies (i.e. quantum instruments) have to be the same. The total number of observers, K, is fixed and known to the observers in the cases ii) and iii). We solve the problems i): for any $d = D$, for any $2 = d < D$, and for any $2 = d < D$ with the restriction of encoding into copies; ii) and iii): for any $d = D$ and for any $2 = d < D$ with the restriction of encoding into copies (leading orders asymptotically, $K \gg D$ and $D \ll K$).

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QUANTUM TOMOGRAPHY OF TWISTED PHOTONS

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We propose a complete tomographic reconstruction of photons carrying orbital angular momentum along their propagation direction. For certain states, the tomographical measurement reduces to the determination of the angular probability distribution at different times of free evolution, which can be measured in the lab [1].

To represent the quantum state we introduce a bona fide Wigner function defined on the discrete cylinder, which is the natural phase space for the pair angle-angular momentum. We discuss the properties of this Wigner function, comparing them with both the discrete and the continuous case [2].

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FRACTIONAL REVIVALS THROUGH ENTROPIC UNCERTAINTY RELATIONS

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We show that generalized uncertainty relations provide a useful framework for visualizing fractional revivals and to investigate properties of the temporal evolution of wave packets, alternative to the usual autocorrelation fuction and expectation value analyses, using three model systems: the simple harmonic oscillator, the infinite square well and the quantum bouncer.

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APPLICATION OF THE BOHR-SOMMERFELD QUANTIZATION TO PHOTONS

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We apply the Bohr-Sommerfeld quantization to photons and show that a photon with an energy ($E = \hbar\omega = hc/\lambda$) carries a quantized magnetic flux tube of ($\Phi = \pm\Phi_0 = \pm hc/e$) with itself is along the propagation direction. Here the plus sign stands for the right hand helicity and the minus sign does for the left hand helicity. We show that the circumference of this tube is exactly equal to the wavelength λ of the corresponding electromagnetic wave. We also derive the relation [$\Phi = (h\omega^2/e^2)\mu$] between the intrinsic flux and the magnetic moment of the photon of as well. Because of the two symmetric values of the magnetic moment, $\mu_z = \pm(ec/\omega)$ (for a photon beam propagating in z-direction), we expect a splitting of the photon beam in two symmetric subbeams in a Stern-Gerlach experiment. The splitting is expected to be more pronounced for low energy photons. We believe that the present result will be helpful for understanding of the Stern-Gerlach experiment with photons and the interaction of photon with matter.

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SPIN DEPENDENT SELECTION RULES FOR PHOTONIC TRANSITIONS IN HYDROGEN-LIKE ATOMS

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Spin dependent selection rules for photonic transitions in hydrogen-like atoms is derived by using the solution of Dirac equation for hydrogen-like atoms. It is shown that photonic transitions occur only when the change in the quantum number $m_j = m_l + m_s$ is ($\Delta m_j = 0, \pm 1$). We distinguish the states in the Zeeman sense including the the quantum number, m_j. Namely: $|n, l, m_j\rangle = |n, l, m_l, m_s\rangle = |n, l, m_l, \downarrow\uparrow\rangle$. We calculate the non-zero matrix elements and then develope and the spin dependent selection rules for the photonic transitions in hydrogen-like atoms. According to the conventional selection rules ($\Delta l = \pm 1$ and $\Delta s = 0$) which are derived from the solution of the Schödinger equation, a transition from ($l = 0$) to ($l = 0$) is not allowed (because $\Delta l = 0$ but not ± 1). However the present selection rules allow the $\Delta l = 0$ transitions as well.

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ELECTRON-POSITRON ANNIHILATION IN TERMS OF THE QUANTUM ENTANGLEMENT AND THE CONSERVATION OF FLUX QUANTUM

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We show that the electron-positron annihilation process resulting with the creation of two gamma photons (with right and left hand circular helicity) can be explained in terms quantum entanglement together with the conservation of the flux quantum. By using the solution of Dirac equations for a free electron (or positron) in a uniform magnetic field, we first show that both electron and positron (which are spin $1/2$ particles) carries an intrinsic flux quantum of $\pm\Phi_0/2$ even in the absence of an external magnetic field. Applying the conservation of energy and the magnetic flux quantum for collisions, we also show that gamma photon carries a magnetic flux quantum of $\pm\Phi_0 = \pm hc/e$ with itself along the propagation direction, Where the $(+)$ and $(-)$ signs correspond to the right hand and left circular helicity, respectively. By using the Heisenberg uncertainty relation and the Bohr-Sommerfeld quantization argument we also prove that any photon carries a magnetic flux quantum of $\pm\Phi_0 = \pm hc/e$ with itself along the propagation direction. Again the $(+)$ and $(-)$ signs correspond to the right hand and left circular helicity, respectively.

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DISSIPATIVE DYNAMICS FOR TWO INTERACTING QUBITS COUPLED TO INDIPENDENT RESERVOIRS

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The master equation of a system of two coupled qubits is derived taking into account their interaction with two independent bosonic baths. Important features of the dynamics are brought to light, such as the stationary state at general temperatures and the behaviour of the entanglement, which shows the phenomena of sudden death and sudden birth as well as the presence of stationary entanglement for long times. The analysis is carried out both at zero and at generic temperatures. The model presented is quite versatile and can be of interest in the study of Josephson junction architectures and of cavity-QED.

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STATE RECONSTRUCTION VIA INFINITE MATRIX INVERSION

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The purpose of our paper [1] is to consider state reconstruction formulas obtained by inverting a suitable (infinite) matrix. We present and compare various different formulas, some of which are well known, and some of which are probably new. We will consider only the case where the Hilbert space of the system is infinite-dimensional, and the experimentally obtainable quantities are well-known (quasi)-probability densities: quadrature distributions, the Q-function, the Wigner function, and general Cahill-Glauber s-distributions.

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THE USE OF THE MICROSCOPIC APPROACH IN THE DESCRIPTION OF ULTRASLOW LIGHT PHENOMENON IN A BOSE CONDENSATE OF ALKALI-METAL ATOMS

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We propose a microscopic approach for a description of processes of interaction of the ideal gas of alkali-metal atoms with a weak electromagnetic radiation. The description is constructed in the framework of the Green-function formalism that is based on a new formulation of the second quantization method in case of the presence of bound states (atoms) [1]. For a gas with the Bose-Einstein condensate (BEC) the dependencies of the propagation velocity and damping rate on the microscopic characteristics of the system are studied [2]. We find conditions when the ultraslow light phenomenon in a BEC of sodium atoms can be observed. We discuss the possibility of microwave signals slowing in BECs. In the framework of the proposed approach the influence of the external homogeneous and static magnetic field on the slowing of electromagnetic waves in the condensate is also studied. It is shown that the velocity of the pulses can be effectively controlled by a bias field [3].

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SUPER INTENSE LASER FIELD ACTION ON SURFACE WITH FORMING ATTO-SECOND LASER PLASMA AND NEW LASER TECHNOLOGY FOR CLEANING THE MATERIALS

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An action of the super short light pulses changes principally a character of interaction of a laser radiation with substance [1]. For laser intensities more than 10^{15} Wt/cm^2 electrons get energy of $100 - 1000$ eV and it is realized a process of forming the femto-second laser plasma.(FLP). We study possibilities of governing by processes, which are taken a place in the FLP in nano-structured porous materials (NSPM; Si). NSPM consist of the separated clusters set with the fractal structure. The key mechanism of the hot electrons generation in plasma is provided by oscillation of electron on the border "plasma-vacuum" or resonant absorption of laser radiation. One may wait for the sharp increasing the hot electrons generation and X-ray radiation. For large laser intensity it is observed a new type of the hydrodynamic ablation. Experimental estimates show that a velocity of the plasma flying of the strongly porous samples Si ($I \sim 3 \times 10^{16}$ W/cm^2) is $\sim 10^8$ cm·s^{-1}, that is $\sim$ to energy 2 ± 1 MeV [2]. We carried out the modelling of FLP forming in the porous materials on the basis of the energy balance equations, the Greens function method and S-matrix formalism [2,3]. Special attention is devoted to the modelling the system: NSPM with clusters, on surface of which there is a great number of bonds with H and OH groups. In a case of D-and OD group's one can wait for realization of cluster explosion process and reaction $D + D \rightarrow \alpha + n$ (3.8 MeV).

Laser photo-ionization and photo-dissociation of molecules method is supposed to be very much perspective method for cleaning the semiconductor materials from molecular admixtures. Laser cleaning of mono-silan represents a great interest for technology of obtaining a poor Si in the semiconductor industry. We propose new optimal schemes of laser photo ionization nano-technologies for control and cleaning the semiconducting substances. Here at first we construct the optimal scheme of the laser photoionization technology for preparing the films of pure composition on example of creation of the 3-D hetero structural super lattices (layers of Ga(1-x)Al(x)As with width 10 Å and GaAs of 60 Å). The scheme of preparing the films of the especially pure composition is based on using the multi-stepped laser photoionization scheme. It includes at first step an excitation of atoms by laser field and their transition into Rydberg states and then ionization by electric field [2]. A creation of the films of pure composition (our problem is creation of the 3-D layers of Ga(1-x)Al(x)As with width 10 Å and GaAs of 60 Å) is directly connected with using the photo ion pensils of Ga, Al, As. Similar pensils can be created by means of the selective photoionization method with ionization by electric field [3].

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GENERATION OF ENTANGLED PHOTON PAIRS IN CHIRPED PERIODICALLY-POLED NONLINEAR CRYSTALS

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Using a rigorous quantum model a comprehensive study of physical properties of entangled photon pairs generated in spontaneous parametric down-conversion in chirped periodically-poled crystals is presented. Spectral, temporal, as well as spatial characteristics of photon pairs are analyzed. Spectral bandwidths, photon-pair flux, and entanglement area can be effectively controlled by chirping. Quantification of entanglement between photons in a pair is given [1,2]. Splitting of entanglement area in the transverse plane accompanied by spectral splitting has been revealed. Using the model temperature dependencies of the experimental intensity profiles reported in literature [3] have been explained. Attention is also paid to poled structures with randomly distributed boundaries.

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AN APPROXIMATE BEAMSPLITTER INTERACTION BETWEEN LIGHT AND ATOMIC ENSEMBLES

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Beamsplitters play vital roles in quantum optics and quantum information for their simplicity and multiple potential uses, such as creating two-mode squeezed states of light, adding/subtracting photons and many others. Although many quantum information protocols require an interaction between light and matter, a similar atom-light beamsplitter transformation has not been realised so far. Here we explore the possibility of achieving a lossless beamsplitter interaction between an incident light field mode and a macroscopic atomic spin ensemble via QND interactions. The light mode L is coupled to an atomic ensemble A via the QND Hamiltonian $\hat{H}_1 = \kappa \hat{P}_L \hat{Q}_A$. The quadratures of both systems are then rotated and the emerging light field is reflected back into the atomic ensemble for a further QND interaction $\hat{H}_2 = -\kappa \hat{Q}_L \hat{P}_A$. Here $\hat{Q}_{L,A}$,$\hat{P}_{L,A}$ represent the position and momentum quadrature operators of the light and atoms. In the case of the atoms, the quadratures represent the re-scaled collective spin operators. The multi-pass QND protocols were studied in [1] for their use in light-state retrieval. Merely two independent subsequent light passes are required in our scheme to generate a beamsplitter-like interaction between light and matter, without any need of interference between the modes.

This interaction transforms the input quadrature states q_1,p_1 and q_2,p_2 for light and atoms respectively as

$$|q_1\rangle_L \, |q_2\rangle_A \rightarrow |q_1 + \phi q_2\rangle_L |(1-\phi^2)q_2 - \phi q_1\rangle_A \quad (1)$$

$$|p_1\rangle_L \, |p_2\rangle_A \rightarrow |(1-\phi^2)p_1 + \phi p_2\rangle_L |p_2 - \phi p_1\rangle_A \quad (2)$$

where ϕ represents the coupling constant, κ, integrated over the interaction time of each pass-through.

We explore the conditions on ϕ and the quadrature distributions which best approximate this interaction to that of a beamsplitter. We then test for which states this approximation holds.

Finally we consider possible applications of this effective beamsplitter interaction. If ϕ is small, it may be possible to use this scheme to increase the entanglement between two entangled atomic ensembles. This could possibly be done by performing beamsplitter interactions on both ensembles, combining the emerging light beams on a real beamsplitter and taking a measurement of one of the light modes. Alternatively, if the fidelity of the interaction remains high as $\phi \rightarrow 0.5$ then this interaction approaches a 50:50 beamsplitter, which has many potential applications in the world of quantum optics.

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DIFFERENT CHANNELS OF RADIATION EMISSION BY IONIZED ELECTRON DURING ITS RESCATTERING IN A STRONG LASER FIELD

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The interaction of strong electromagnetic field with different atomic and molecular quantum systems is one of the most interesting problem of the modern laser physics. In the case of strong-field ionization of an atom or a molecule the electron in the continuum oscillates (as an almost free) in the laser field, and can return and re-collide with the parent ion [1]. During this rescattering the electron can recombine back to the bound state, or the transition to the lower energy state in the continuum can take place. In both cases one or several photons are emitted. Since the electron energy in the continuum is determined by the specific features of the ionization process and results from absorption of several laser photons in above-threshold ionization regime [2], the energy of photon, emitted during the recombination process is usually equal to the odd number of quanta of the interacting laser field. The emitted radiation is referred to as high harmonic generation (HHG) and is under intent theoretical and experimental investigation now due to a lot of its practical applications [2]. Usually, the HHG process is only considered as a result of the recombination to the bound state and is interpreted classically as a radiation of a charged particle, accelerated by a potential centre (ion). The correspondence between this semi-classical description and fully quantum mechanical approach to the problem of radiation emission in the process of electronion recollision as well as the role of different emission channels including free-free electron transition and the influence of a present strong classical laser field remains still unclear.

In this work the emission of radiation by electron during its rescattering on the parent ion is investigated fully quantum-mechanically in the frame of perturbation theory. Different channels of the radiation emission are considered and the competition between them is discussed. The spontaneous emission is considered both in the case of recombination to the bound state and for transitions to the low-lying continuum states. In the case of continuum-continuum transitions for the electron, the eigenfunction of the system "free electron + quantized electromagnetic field" are used and the interaction with the quantum field is taken into account explicitly. In this case the process of multiphoton spontaneous emission can be considered. The influence of the presence of external classical laser field ionizing the atomic system on the process of emission of radiation to different modes of a quantum field is analyzed. The obtained results are compared with the semi-classical approach to the HHG and with numerical data obtained by direct numerical integration of the non-stationary Schroedinger equation for a 3D atom in a strong laser field.

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PHASE SHIFTS IN NONRESONANT COHERENT EXCITATION

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Far-off-resonant pulsed laser fields produce negligible excitation between two atomic states but may induce considerable phase shifts. The acquired phases are usually calculated by using the adiabatic-elimination approximation [1]. We analyze the accuracy of this approximation and various sources of imperfections, ranging from higher terms in the adiabatic-elimination expansion to couplings to additional states. We demonstrate that, as far as the dynamic phases are concerned, the adiabatic elimination is sufficiently accurate only for a *very* large detuning. We show that the *adiabatic approximation* [1] is a far more accurate method for evaluating the phase shift, with a vast domain of validity; the accuracy is further improved substantially by superadiabatic corrections. Moreover, owing to the effect of adiabatic population return, the adiabatic and superadiabatic approximations allow one to calculate the phase shift with even a moderately large detuning. We also derive several exact expressions for the dynamic phase using exactly soluble two-state and three-state analytical models.

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TRUSTED AND UNTRUSTED NOISE IN QUANTUM CRYPTOGRAPHY WITH NOISY COHERENT STATES

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In the present contribution we address the security of quantum cryptography scheme based on the coherent states in the presence of preparation noise (i.e. noisy coherent states) in the realistic conditions which include losses and noise of different origins. The security analysis is performed in both individual and collective attacks scenarios. The noise in the transmission is considered to be untrusted, i.e. available for eavesdropper, while the local sending and remote measuring stations are assumed to be secure, meaning that detection and preparation noise is trusted. We show the possibility to provide the security of the key upon purely trusted noise for any level of preparation noise by means of local manipulations (attenuation) on the sender side, extending the method proposed in [1]. We reveal the essential difference between trusted and untrusted noise and establish bounds on the untrusted channel noise limiting the security of the scheme. We develop the framework for the security analysis of the scheme in the presence of different types of noise and find the expressions fitting the maximal key rate secure against collective attacks upon optimal attenuation and untrusted channel noise, which can be used to estimate the experimental applicability of the scheme in particular real conditions.

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A FULL QUANTUM-MECHANICAL LASER-MODEL

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Closed bipartite quantum systems may exhibit relaxation behaviour with respect to a subsystem [1]. Here we investigate a full quantum-mechanical laser-model comprised by a finite spin-network with one interfacing spin being coupled to a single field mode via Jaynes-Cummings-interaction.The spin-subsystem is intially prepared in a high energy state implying an effective negative temperature for the interfacing spin. The pure state of the system evolves entirely under Schroedinger-dynamics, but, nevertheless, shows relaxation towards a state with increased field energy. The properties of the cavity-field are examined with quantum-optical methods (e.g. photon statistics). We show that during relaxation the field mode state is a phase-diffused Glauber state with no coherence. This is in accord with the claim by K. Mollmer [2], who questioned the existence of optical coherence in typical laser sources.
Thermodynamical aspects of our system are consistent with this finding: The so called LEMBAS-scheme [3] is a method to systematically split energy exchange between a system and its environment into work and heat. We show that in the present case the energy exchange between both subsystems is indeed heat only.

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TIME-DEPENDENT MAXWELL FIELDS AND ENERGY DENSITIES FOR AN ATOM IN FRONT OF A CONDUCTING WALL

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In 1948 Casimir and Polder predicted the existence of attractive forces of quantum nature between two polarizable atoms or molecules in their ground state [1]. In the context of quantum electrodynamics such interactions, namely Casimir-Polder forces, can be simply derived invoking the existence of quantum vacuum fluctuations. The presence of macroscopic boundary conditions, such as metallic or dielectric bodies, can modify vacuum fluctuations, thus leading to a different behavior of the Casimir-Polder interatomic interaction.

In the last decades these forces have been studied in different physical situations. One important case is that of time-dependent Casimir-Polder interactions. In [2] the authors studied the properties of the electromagnetic field operators in the Heisenberg picture around an atom in the free space. They considered an initially bare ground-state atom and showed that the time evolution of the atom-field system leads to time-dependent Casimir-Polder interactions.

Using the same method of [2] we study the time evolution of the electric and magnetic field operators in the case of a single atom in front of an infinite and perfectly conducting wall [3]. We show that our results can be physically interpreted as the superposition of the field propagating directly from the atom and the field reflected by the wall. Considering the case of an initially bare ground-state atom, we apply the results obtained to the calculation of the time-dependent electric and magnetic energy densities. These quantities are directly related to the far-zone limit of the Casimir-Polder interaction with a second atom when the conducting wall is present. Our results are not limited to a specific initial state, thus the same method can be used for initial bare excited states or partially dressed states.

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INTERFERENCE CONTRAST IN FEW PHOTON OPTICS. PART II

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Currently, many quantum information experiments are realized with pairs of entangled photon produced in down-conversion. The properties of this process may, however, impair the multiphoton interference visibility. This is caused, for example, by the emission statistics (compare the poster of W. Laskowski), but also by the energy-time correlation within a pair. The poster presents quantitative analysis of how the temporal dependences, and introducing spectral filters to an optical setup influences correlations observed in the experiment.

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