P1

SPATIAL ADIABATIC PASSAGE OF LIGHT AND SOUND WAVES

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We present the spatial adiabatic passage (SAP) of light in a system of three evanescent-coupled silicon oxide total internal reflection waveguides. We have experimentally verified that it is possible to achieve a robust, in front of technological variations, and highly efficient transfer of light between the outermost waveguides of the system. Thus, SAP of light represents a powerful alternative to directional couplers. The SAP of light was already reported previously as a proof of principle. However, we show its first experimental implementation in CMOS-compatible technology, which could allow for massive and low-cost fabrication of these devices and their incorporation in realistic photonic integrated circuits. Additionally, using the same technology, we experimentally demonstrate the use of this system as a high- and low-pass spectral filter taking advantage of the fact that the coupling strength depends on the wavelength. Due to its robustness against technological variations and its low cost, this SAP spectral filter presents an alternative to interference-based and absorbance- based filters.

In this work we also discuss, for the first time to the best of our knowledge, the application of SAP processes to sound waves propagating in sonic crystals with linear defects. By modifying the geometry of the linear defects along the propagation direction and studying the projected band diagrams obtained using the plane wave expansion method, we design a coherent multifrequency adiabatic splitter, a phase difference analyzer and a coherent multifrequency adiabatic coupler.

P2

QUANTUM STATE SPECIFIC REACTANT PREPARATION IN A MOLECULAR BEAM BY RAPID ADIABATIC PASSAGE

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Efficient quantum state specific reactant preparation is achieved in a molecular beam using tunable infrared (IR) radiation from a single mode continuous wave optical parametric oscillator (cw-OPO). With appropriate focusing of the IR radiation, molecules in the molecular beam crossing the IR field experience a Doppler tuning that can be adjusted to achieve complete population inversion of a two-level system by rapid adiabatic passage (RAP). A room temperature pyroelectric detector is used to monitor the excited fraction in the molecular beam and the population inversion is detected and quantified using IR bleaching by a second IR-OPO. The second OPO is also used for complete population transfer to an overtone or combination vibration via double resonance excitation using two spatially separated RAP processes.

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P3

MQDT-ASSISTED HIGH-RESOLUTION SPECTROSCOPY OF THE RYDBERG STATES OF H_2 – IONIZATION ENERGY OF H_2 AND ROVIBRATIONAL STRUCTURE OF H_2^+

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H_2^+ and H_2 are the simplest of all molecules and as such are important molecules for the development of molecular quantum mechanics. The rovibrational energy-level structure of H_2^+ and H_2 can be calculated extremely precisely by quantum chemical methods which include the determination of relativistic and quantum-electrodynamic effects [1,2]. Because the rotational and vibrational transitions of H_2^+ are electric- dipole forbidden, the experimental data on its energy-level structure are limited.

We present studies of multiphoton transitions to Rydberg states of H_2 belonging to states converging to a wide range of rovibrational levels of H_2^+ X^+ ($^2\sigma_g^+$; v^+=0-12, N^+=0-6) at high spectral resolution. By extrapolating the Rydberg series using multichannel quantum-defect theory the vibrational, rotational, fine- and hyperfine-structure intervals of H_2^+ can be determined precisely [3,4]. The same data can also be used to determine the ionization and dissociation energies of H_2 [5].

Using a home-built pulsed near-infrared laser with Fourier-transform-limited linewidth and adjustable pulse duration, in combination with an improved multiphoton-excitation scheme, we have recently improved the accuracy of these measurements. To this end, systematic errors originating from ac and dc Stark shifts, from pressure shifts, and from the frequency shifts and chirps accompanying the generation of the NIR laser pulses were quantified and minimized.

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P4

EFFICIENT POLARIZATION OF HIGH ANGULAR MOMENTUM SYSTEMS

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We propose a method of optical pumping that is applicable to open, high-angular-momentum transitions in atoms and molecules, for which conventional optical pumping would experience significant population loss. Instead of applying circularly polarized cw light, as in conventional optical pumping, we propose to induce coherent population transfer with repeated pulses of $\sigma+$ and σ- light (using, for example, the technique of adiabatic fast passage), to arrange the atoms so that the maximum amount of entropy is removed from the system with each spontaneous decay from the upper state. This minimizes the number of spontaneous-emission events required to produce a stretched state, thus reducing the population loss due to decay to other states. Simple estimates for the efficiency of the proposed method are given, along with the results of a numerical simulation, showing an efficiency that can exceed that of conventional optical pumping by greater than an order of magnitude for systems with J 100. In addition, the proposed method can be used for efficient optical pumping on an open $J \to J' = J + 1$ transition, for which conventional optical pumping is ineffective.

P5

THREE-PHOTON STIRAP-LIKE SCHEME FOR MANY-ATOM SAMPLES

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A STIRAP-like scheme is proposed to exploit a three-photon dark resonance taking place in alkaline-earth-metal ions. A three photon coherent population trapping in calcium like ions has been identified [1] and could be used in a STIRAP like process to coherently transfer the population from one metastable state to the other one. This scheme is designed for state transfer between the two fine structure components of the metastable D-state which are two excited states that can serve as optical or THz qubit. The advantage of a coherent three-photon process compared to two-photon STIRAP lies in the possibility of exact cancellation of the first order Doppler shift which opens the way for an application to a sample composed of many ions. The transfer efficiency and its dependence with experimental parameters are analysed by numerical simulations. This efficiency is shown to reach a fidelity as high as $1 - 8 \times 10^{-5}$ with realistic parameters. The scheme is also extended to the synthesis of a linear combination of three stable or metastable states [2].

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P6

QUANTUM CONTROL VIA GEOMETRICAL OPTIMIZATION

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The selective preparation of arbitrary states by means of laser protocols is a paramount goal of quantum control, one that has primary importance in quantum engineering, particularly in quantum information or quantum computation processes. In this work we will analyze general features of some control schemes assuming certain constrained controllability criteria [1]. To that end we will use the Rayleigh-Ritz approach applied to the time-evolution operator, maximizing transition probabilities. This approach is equivalent to a geometrical optimization of the dynamics where the time evolution operator is replaced by an ordinary rotation in a subset of the Hilbert space.

We will be concerned with intrinsic properties of the dynamics of systems with manifolds of sublevels, which pose several interesting problems from the point of view of controlling the system dynamics. Quantum control typically implies the ability to manipulate interfering pathway [2]. With a larger number of levels participating in the dynamics, a multilevel structure should offer more control opportunities at the expense of our ability to manipulate the wave function within the substructure. However, as shown, such multi-level structures often give raise to Stark effects that actively block population transfer [3]. Only by cleverly engineering the quantum state of the system, and not by a brute force approach, can one invert the population between states in a multilevel structure such as a molecule. In particular, using a novel scheme termed parallel transfer, we will show that one can achieve ultrafast population inversion with minimal pulse intensities and practically overcome the tyranny of the pulse area theorem, as long as all initial sublevels can be accessed. However, to prepare arbitrary superposition states one needs to have full controllability on to both the initial and the final manifold of sublevels.

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P7

TIME-OPTIMAL DRIVING AND QUANTUM SPEED LIMIT OF NONLINEAR TWO-LEVEL SYSTEMS

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The time-optimal driving and quantum speed limit for the generalized nonlinear two-level systems are investigated with the applications in Bose-Einstein condensate and nonlinear optics. We derive the time-optimal protocols to achieve minimal time required to drive a general initial state to a final state by a nonlinear Landau-Zener-type Hamiltonian. The relevant quantum speed limit of nonlinear two-level systems are finally discussed.

P8

MICROWAVE STIMULATED RAMAN ADIABATIC PASSAGE USED FOR INTERNAL STATE CONVERSION OF A MAGNETICALLY TRAPPED BOSE-EINSTEIN CONDENSATE

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STIRAP [1-3] was first demonstrated with molecular beam [1], and has proven to be a versatile tool for quantum information [4] and atomic physic [5-6]. In this abstract, we report the use of stimulated Raman adiabatic passage (STIRAP) [2,3] in the microwave frequency range (around 6,8 GHz) to change the internal state of a Bose-Einstein condensate trapped in a magnetic potential in the vicinity of an atom chip [7]. Using stimulated Raman adiabatic passage between the Zeeman levels of the two hyperfine ground state levels of rubidium, we produce a condensate in the hyperfine level $|F = 2, m_F = 1\rangle$ of the $5^2S_{1/2}$ ground state of ^{87}Rb by spin flipping around 87% of the atoms of a Bose- Einstein condensate originally prepared in the spin state $|F = 2, m_F = 2\rangle$. To overcome the losses due to the anti-trapping behaviour of the intermediate state $|F = 1, m_F = 1\rangle$ and to mitigate the collisional losses in the final STIRAP state $|2, 1\rangle$, we found non-zero conditions on the one and two-photon detunings which maximize the transfer efficiency. This conditions are confirmed by our experimental measurements and by a theoretical model based on a set of quantum Liouville equations with atomic losses and gains.

We choose to use STIRAP because this protocol allows a population transfer to the target state $|2, 1\rangle$ with no population in the other states with resonant fields [2,3] which permit a fast population transfer. The most straightforward protocol, namely one-photon Rabi oscillations, would spread the atoms in all (equally spaced) Zeeman sub-levels of the $F = 2$ manifold. For two- photon Rabi oscillations, the one-photon detuning needed to avoid population in the intermediate state $|1, 1\rangle$ would result in a longer transfer time than the STIRAP. This technique allows us to cool an atomic cloud in $|2, 2\rangle$ and then to prepare it in state $|2, 1\rangle$ for interferometric purposes as described in [8]. Preparing the condensate in $|2, 2\rangle$, whose magnetic moment is twice as big as other trappable hyperfine levels of the ^{87}Rb ground state, has the advantage of bigger magnetic forces for equivalent electrical power dissipation allowing to increase trap confinement and thus to perform faster evaporative cooling.

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P9

EFFECTIVE MODELS FOR QUANTUM PLASMONICS: APPLICATIONS FOR LASER-DRIVEN NANOSPHERES

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Quantum plasmonics benefits from the strong confinement of the surface plasmon polariton (SPP) that ensures efficient coupling at a deeply subwavelength scale. This paves the way to ultrafast quantum control at the nanoscale. Here, we present our results in connecting the effective models in cavity QED with a full quantisation of a lossy physical system based on its Green's tensor. We discuss the modal analysis of the response (the Green's tensor) of the system. Subsequently, we show the essential steps in accomplishing the non-trivial task of building an effective cavity QED model starting from the full, Green's tensor based quantization. Quantising the system using the dyadic Green's function (also known as Green's tensor) of the environment of the atoms makes it possible to determine the value of the effective atom-field coupling constants as a function of the atomic positions as well as the geometry and electromagnetic properties of the environment. Note that we can easily introduce intrinsic material losses in the system through macroscopic parameters (electric permittivity, magnetic permeability). With this combined toolbox we can apply cavity QED in systems differing from conventional optical cavities but still possessing strong electromagnetic resonances. Specifically, we use this approach for investigating the behaviour of systems containing quantum dots which interact with plasmonic resonances of a silver nanosphere where also driving with external lasers is possible.

P10

ADIABATIC PASSAGE WITH LIGHT INDUCED POTENTIALS

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Adiabatic Passage with Light induced Potentials (APLIP) uses a STIRAP-like sequence of pulses to achieve adiabatic transfer between molecular potentials involving many vibrational states and avoiding the need for Franck-Condon overlaps. The APLIP process will be presented and the differences and similarities between APLIP and STIRAP will be highlighted.

P11

PHASE-INSENSITIVE MAPPING OF COHERENCES ONTO LONG-LIVED POPULATIONS

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Storage of optical information in quantum systems typically relies on atomic coherences, i.e. coherent superpositions of states. During storage, the atomic coherences are subject to decoherence, which destroys the encoded information. Various protocols have been implemented to reduce the effects that lead to decoherence, e.g. dynamical decoupling. However, these protocols are usually rather complicated, which leads to difficulties in their implementation.

We theoretically develop a novel phase-insensitive coherence population mapping (CPM) protocol for storage of coherences well beyond the decoherence time of a system up to the population relaxation time. The information about the coherence is written in the populations of a three- state system by a composite sequence of phase shifted pulses requiring only two coupling fields (or a single field with two different polarizations), which allows for a wide variety of experimental implementations. After the storage, the full information about the stored coherence is distributed equally among all three coherences of the system. The retrieval efficiency is insensitive to the phase of the stored signal unlike other well known storage protocols, e.g., the well known stimulated-photon echo.

P12

ENHANCEMENT OF ULTRACOLD MOLECULE FORMATION USING SHAPED NANOSECOND FREQUENCY CHIRPS

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We demonstrate that judicious shaping of a nanosecond-time-scale frequency chirp can dramatically enhance the formation rate of ultracold molecules. Starting with ultracold 87Rb atoms, we apply pulses of frequency-chirped light to first photoassociate the atoms into excited molecules and then, later in the chirp, de-excite these molecules into a high vibrational level of the lowest triplet state. The enhancing chirp shape passes through the absorption and stimulated emission transitions relatively slowly, thus increasing their adiabaticity, but jumps quickly between them to minimize the effects of spontaneous emission. Comparisons with quantum simulations for various chirp shapes support this enhancement mechanism.

P13

CREATION OF ^{87}RBCS MOLECULES IN THE ROVIBRATIONAL GROUND STATE

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Ultracold and quantum degenerate mixtures of two or more atomic species open up many new research avenues, including the formation of ultracold heteronuclear ground-state molecules possessing a permanent electric dipole moment [1]. The anisotropic, long range dipole-dipole interactions between such molecules offer many potential applications, including novel schemes for quantum information processing [2] and simulation [3]. Heteronuclear ground-state molecules have been created in KRb [4] and, very recently, in RbCs [5]. Here we present our recent results including, the complete Feshbach spectroscopy of an ultracold ^{85}Rb-Cs mixture [6] and the formation of ultracold Cs_2 and ^{87}RbCs Feshbach molecules [7,8]. Finally we show a simple design for a tuneable, narrow-linewidth, two-colour laser system [9] and demonstrate transfer of the ^{87}RbCs Feshbach molecules into the rovibrational ground state via Stimulated Raman Adiabatic Passage (STIRAP) [10].

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P14

SPATIAL ADIABATIC PASSAGE WITH HIGHER SPIN SYSTEMS

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The adiabatic transfer of a quantum superposition state through a spin-1/2 chain via time-varying spatial couplings is a well-known analogue to STIRAP. This process transfers not only population but quantum information spatially, as the phase relation to the ground state is preserved, and even enables the creation of entanglement via branched networks. We discuss the adiabatic transport of an arbitrary superposition state between spin-1 sites, i.e. qutrit transport, (and higher), and its dependence on the initial state of the other sites, the bus states. For 3-site qutrit transport there are precisely 5 bus states. We furthermore discuss branched networks for higher spin systems with multiple recipients and quantify the entanglement created. We find that maximal entanglement is only possible for two spin-1/2 sites, due to an egalitarian principle, which aims to distribute a multiply excited state over several recipient states.

P15

MOLECULAR BEAM AND ULTRACOLD MOLECULE PRODUCT SPECTROSCOPY FOR IDENTIFYING PATHWAYS

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Stimulated Raman Adiabatic Passage (STIRAP) has been used in transferring from ultracold molecules (UM) in an internally high energy state into the lowest energy ground state, which has been of particular interest to the ultracold community because UMs in the lowest state cannot undergo inelastic collisions as T $\rightarrow$ 0K, and therefore are promising candidates for degenerate Bose and Fermi gases. We have been combining diatomic spectra of molecular beam (MB) experiments and UM experiments. We focus here on the heteronuclear KRb molecule. The combination allows definitive assignments of nearly all lines in the mutually strongly perturbed $A\,^1\Sigma^+ - 3\,^1\Sigma^+ - 1\,^1\Pi - 2\,^3\Sigma^+ - b\,^3\Pi$ states of ultracold $^{39}K^{85}Rb$ molecules if the same energy regions of the excited states involved are covered in the spectra. Moreover, it can be used to identify the optimum pathways for STIRAP from translationally ultracold molecules formed in high rovibrational levels near the ground state dissociation limit to translationally and rovibrationally ultracold molecules in the lowest rovibrational level of the ground electronic state, even when spectral assignments are unavailable. We are also interested in transferring population from selected near dissociation levels to higher levels with very large outer turning points for observation of trilobite-like states.

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P16

TIME-DEPENDENT QUANTUM DYNAMICS: A GLOBAL ITERATIVE METHOD WITHIN THE WAVE OPERATOR FORMALISM

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A global iterative algorithm is developed to solve the time-dependent Schrödinger equation. We use the time-dependent wave operator formalism in which the dynamics is formally separated into a simple evolution within a low-dimensional active subspace and a secondary evolution from the subspace to the complementary space (given by the wave operator). A fast iterative algorithm is developed in which numerous time integrals over time have to be calculated. The use of a Fourier basis set to describe the time dependencies avoids the need for very short time steps. The global method is competitive with standard step by step propagation algorithms. The first illustrative example is an asymmetric double well model submitted to laser pulses in a STIRAP configuration. Some results on the adiabatic vibrational purification of H_2^+ are also presented.

P17

FESHBACH TO ULTRACOLD MOLECULAR STATE RAMAN TRANSITIONS IN A SEVEN-LEVEL SYSTEM USING OPTICAL FREQUENCY COMBS

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A method for a creation of molecules in the ultracold state from the Feshbach molecules by stepwise adiabatic passage using an optical frequency comb is investigated in the framework of a semiclassical seven-level system. Sinusoidal modulation in both the time domain and the frequency domain across an individual pulse in the pulse train is applied that leads to a creation of a quasi-dark state minimizing population of the transitional, vibrational state manifold and efficiently mitigating decoherence in the system. The parity of the chirp shown to be an important factor in designing population dynamics in the system.

P18

PULSE-TRAIN STIRAP IN MULTILEVEL QUANTUM SYSTEMS

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We consider coherent population transfer in multilevel quantum systems driven by time-delayed pulse trains. It is shown that the efficient population transfer in a Λ-type three-level system can be achieved without partial overlap of the pump and the Stokes sub-pulses of the pulse trains. Generalized straddling STIRAP scheme of the population transfer in N-level system with sequential coupling is also examined. The mechanism of the population transfer and the robustness of the proposed scheme are discussed.

P19

SUBWAVELENGTH LOCALIZATION VIA ADIABATIC PASSAGE: NANOLITHOGRAPHY, COHERENT PATTERNING OF MATTER WAVES, SINGLE-SITE ADDRESSING IN OPTICAL LATTICES, AND NANOSCOPY

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We discuss the Subwavelength Localization via Adiabatic Passage (SLAP) technique to coherently achieve state-selective localization beyond the diffraction limit. The SLAP technique consists in coupling two partially overlapping and spatially structured laser fields, e.g., presenting intensity nodes, to an ensemble of three-level atoms yielding state-selective localization at those positions where Stimulated Raman Adiabatic Passage does not occur. The main advantages of SLAP compared to other techniques are: (i) it is a fully coherent process that does not rely on spontaneous emission and, therefore, it can be applied to open three-level systems and to systems where coherence has to be preserved such as BECs; (ii) the localized state does not suffer from recoil induced broadening and, therefore, the Raman-Nath approximation holds, and, finally, (iii) it is robust under uncontrolled variations of the system parameters, e.g., intensity fluctuations of the laser fields.

In this work, we describe the basics of the SLAP technique and derive semi-analytical conditions for achieving the "superlocalization" regime as well as its potential implementation for matter wave lithography down to the single nanometer scale and for coherent patterning of a BEC at the Heisenberg limit. Moreover, we propose a single-site addressing protocol based on SLAP and discuss its implementation for Rb-87 atoms in state-of-the-art optical lattices. Finally, we investigate the use of the SLAP technique for fluorescence microscopy with nanoscale resolution in the far field, deriving an analytical expression to assess the resolution and performing a comparison with the coherent population trapping and the stimulated-emission-depletion techniques.

P20

HYPERFINE STRUCTURE CALCULATION FOR EXCITED STATES OF BIALCALINE MOLECULES FOR ULTRACOLD MOLECULAR FORMATION BASED ON STIRAP

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High efficiency production as well as the confinement and manipulation of ultracold molecules with external fields require a precise knowledge of their level structure. The transfer of the initially weakly bound ultracold molecules to their absolute rovibrational ground level, relies on the existence of suitable electronically excited states allowing an efficient stimulated Raman adiabatic transfer (STIRAP). Due to the complexity of the problem little is known about the hyperfine structure of molecular states, in particular for the electronically excited states. We propose an asymptotic model where the molecular hyperfine interactions are determined by the atomic hyperfine interaction [1]. This assumption is strictly valid for large internuclear distances when the exchange energy between the two atoms is negligible. At shorter distances, the variation of the electronic current is expected to be small enough to allow the model for catching the essential of the hyperfine splitting of the molecular levels. As a first step, we have determined potential energy surfaces (PES) for any internuclear distance considering the molecular spin-orbit and hyperfine interactions for a non-rotating molecule. We will present our results on the hyperfine structure for the bosonic $^{39}K^{133}Cs$ and fermionic $^{40}K^{133}Cs$ molecule for excited molecular states which correlate to the K(4 ^2S) + Cs(6 $^2P_{1/2,3/2}$) limit.

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P21

STATE TRANSFER IN STATIC AND DYNAMIC SPIN CHAINS

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Reliable quantum channels, based on, for example, spin chains, are indispensable for achieving scalable and efficient quantum information processing and communication in solid-state systems with fixed qubit positions and finite-range interqubit interactions. We have studied several protocols for complete state or excitation transfer in static and dynamic spin chains and examined their speed and sensitivity to diagonal and off-diagonal disorder. In particular, we have found that, for a given chain length and maximal achievable interspin exchange (XY) coupling strength, the optimal static spin-coupling protocol, implementing the fastest state transfer between the two ends of the chain, is more susceptible to off-diagonal (XY coupling) disorder, as compared to a much slower but robust adiabatic transfer protocol with time-dependent coupling strengths, which is based on the multistate STIRAP.

P22

ADIABATIC CREATION OF COHERENT SUPERPOSITION STATES IN A TWO-LEVEL ATOMIC SYSTEM WITH ZEEMAN SPLITTING

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We study a two-level atomic system interacting with three single-frequency, differently polarized optical fields in the presence of magnetic field that removes degeneracy of atomic levels. We investigate a possibility of obtaining a coherent superposition states in such a system using a STIRAP-like method proposed in [1]. We show that in spite of the fact that the two-photon resonance condition is not exactly satisfied it is possible to obtain a coherent 50:50 superposition by a proper choice of the parameters of the system. Such a configuration may have applications in construction of atomic beam splitters and Hadamard gates.

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P23

TRIPOD ANALOGUES IN OPTICAL WAVEGUIDES – ADIABATIC 50:50 SUPERPOSITION OF WAVEGUIDE MODES

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We consider a system of three optical waveguides linearly coupled to a central waveguide with a coupling strength adiabatically varying with distance, in analogy with STIRAP-like adiabatic passage process in atomic system with TRIPOD configuration. We study a possibility of obtaining 50:50 superposition of waveguide modes, which can have an application in construction of optical beam splitters and Hadamard gates.

P24

LOADING AND TRANSPORT OF MATTER-WAVES IN RING POTENTIALS VIA SPATIAL ADIABATIC PASSAGE

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In this work we investigate Spatial Adiabatic Passage (SAP) processes for single atoms trapped in the ground state of cylindrically symmetric potentials. Specifically, we use a matter-wave RAP-like process to load a single atom from a harmonic potential to a ring potential in a very robust way and also to study the transport of an atom between two concentric ring potentials. In the RAP-like processes we vary the frequency and the radius of the outer ring potential to adiabatically follow an eigenstate of the system obtaining a full transfer of the atom between the two minima of the potentials. We also study a matter-wave STIRAP-like process between three concentric ring potentials showing that the transport of a single atom between the innermost and the outermost ring potentials can be performed following the spatial dark state of the system.

We characterize the dynamics by means of a two-state and a three-state model for the RAP-like and STIRAP-like processes, respectively. The analytical results are compared with the numerical solution of the two-dimensional Schrödinger equation finding a good quantitative agreement for both SAP processes. We also analyze the robustness of the two processes in front of variations of the parameters of the system.

P25

ADIABATIC PASSAGE MEDIATED BY PLASMONS: A ROUTE TOWARDS A DECOHERENCE-FREE QUANTUM PLASMONIC PLATFORM

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We show that strong coupling in quantum plasmonics can be used to mediate efficiently the interaction between emitters when the dynamics are driven along a dark state immune to the strong plasmon loss. This is achieved via a stimulated Raman adiabatic passage induced by laser pulses driving the emitters. We develop, from a fully quantized Hamiltonian of surface plasmons based on the Green tensor, a general toolbox which allows one to derive effective multimode models. Highly efficient and robust population transfer, as well as the deterministic generation of entanglement between emitters are numerically shown. These results pave the way for an efficient use of the quantum plasmonic platform beyond its inherent losses.

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HIGH RESOLUTION MOLECULAR SPECTROSCOPY OF AN ULTRACOLD ^{23}NA-^{40}K MIXTURE

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Ultracold quantum gases with long-range dipolar interactions promise exciting new possibilities for quantum simulation of strongly interacting many-body systems. One way to realize a system with this interaction is to create an ultracold sample of ground state polar molecules. Since direct cooling of molecules is difficult due to their complex internal structure, in our setup sodium and potassium atoms are cooled close to quantum degeneracy first. Via an interspecies Feshbach resonance they are then associated to weakly bound molecules. To obtain molecules in their absolute vibrational, rotational and hyperfine ground state we want to implement stimulated Raman adiabatic passage (STIRAP), a two-photon process capable of transferring weakly bound Feshbach molecules via an intermediate, excited molecular state to the ground state with high efficiency. Intermediate molecular levels with sufficiently large transition matrix elements to both the initial and the final state can be found in the d/D-potentials of ^{23}Na-^{40}K. Here we will present recent spectroscopy results from this intermediate state manifold. In addition we investigate under which conditions a dark state between our STIRAP levels exists and explore its properties.

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ADIABATIC INVARIANTS AND CONSERVATION LAWS FOR PSEUDO-HERMITIAN QUANTUM SYSTEMS

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In many contexts, a need arises to study the so called pseudo-Hermitian operators unlike the traditional Hermitian operators in quantum mechanics. Applications of pseudo-Hermitian Hamiltonians range from a possible extension of the fundamentals of quantum mechanics to description of optical microspiral cavities, description of electrons in gravitational fields of rotating objects, describing Maxwell equations in pseudo-Hermitian form, describing quantum effective Hamiltonians of interactions etc. We derive nonlinear laws of conservation for a rather general pseudo-Hermitian matrix with arbitrary dimensions. In particular we study the adiabatic approximation for a two and three level pseudo-Hermitian matrix. We derive the adiabatic invariants in these cases and compare them with the usual Hermitian case.

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ULTRAFAST QUANTUM CONTROL VIA PARALLEL TRANSFER

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The selective preparation of arbitrary states by means of laser protocols is a paramount goal of quantum control, one that has primary importance in quantum engineering, particularly in quantum information or quantum computation processes. In this work we will analyze general features of some control schemes assuming certain constrained controllability criteria. To that end we will use the Rayleigh-Ritz approach applied to the time-evolution operator, maximizing transition probabilities. This approach is equivalent to a geometrical optimization of the dynamics where the time evolution operator is replaced by an ordinary rotation in a subset of the Hilbert space.

We will be concerned with intrinsic properties of the dynamics of systems with manifolds of sublevels, which pose several interesting problems from the point of view of controlling the system dynamics. Quantum control typically implies the ability to manipulate interfering pathways. With a larger number of levels participating in the dynamics, a multilevel structure should offer more control opportunities at the expense of the ability to manipulate within the substructure. However, as we will demonstrate, substructures often give raise to Stark effects that actively block population transfer. A balance must therefore take place between the number of levels that participate in the dynamics and those that can be controlled and to what extent. Defining different ways to set up this balance, our general goal is to investigate whether quantum structures limit, or conversely help, in controlling the system.

We will show that coarse grain population passage between manifolds can be made faster via a novel control scheme termed parallel transfer. By suitably preparing particular initial superposition states one can almost overcome the tyranny of the pulse area theorem, as long as all initial sublevels can be accessed. However, to prepare arbitrary superposition states one needs to have full controllability on to both the initial and the final manifold of sublevels.

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COMPOSITE STIRAP

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We introduce a high-fidelity technique for coherent control of three-state quantum systems, which combines two popular control toolsstimulated Raman adiabatic passage (STIRAP) and composite pulses. By using composite sequences of pairs of partly delayed pulses with appropriate phases, the nonadiabatic transitions, which prevent STIRAP from reaching unit fidelity, can be canceled to an arbitrary order by destructive interference, and therefore, the technique can be made arbitrarily accurate. The composite phases are given by simple analytic formulas, and they are universal for they do not depend on the specific pulse shapes, the pulse delay, and the pulse areas.

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UNAMBIGUOUS ATOMIC BELL MEASUREMENT ASSISTED BY MULTIPHOTON STATES

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We propose and theoretically investigate an unambiguous Bell measurement of atomic qubits assisted by multiphoton states. The atoms interact resonantly with the electromagnetic field inside two spatially separated optical cavities in a Ramsey-type interaction sequence. The qubit states are postselected by measuring the photonic states inside the resonators. We show that if one is able to project the photonic field onto two coherent states on opposite sites of phase space, an unambiguous Bell measurement can be implemented. Thus our proposal may provide a core element for future components of quantum information technology.

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TIME SYMMETRIC SINGLE PHOTON WAVE PACKETS FOR FREE SPACE QUANTUM COMMUNICATION

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We propose a procedure to achieve high fidelity conversion between a photonic qubit encoded in a single photon wave packet and a matter qubit encoded in the atomic level structure of a single atom in free space with a high success probability. This procedure makes use of stimulated Raman adiabatic passage in order to control the interaction between the atom and the radiation field. Thereby, a matter qubit can be converted into a photonic qubit stored in a time-symmetric single photon wave packet which can be absorbed almost perfectly by a second atom due to time reversal symmetry. By absorbing such a single photon wave packet, the photonic qubit can be converted back into a matter qubit thereby achieving a high fidelity quantum state transfer between distant matter qubits. In contrast to already known schemes, the protocol proposed in this article does not rely on high finesse cavities and optical fibers and is compatible with a free space communication channel.

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THE HETERONUCLEAR EFIMOV EFFECT IN AN ULTRACOLD BOSE-FERMI MIXTURE OF ^{133}CS AND ^{6}LI ATOMS

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The Efimov scenario, where pairwise resonantly interacting particles form an infinite geometrical series of bound three-body states, the Efimov states, is one of the most fundamental effects in modern quantum mechanics. The theoretical understanding and experimental observation of such progressions in both homonuclear and heteronuclear systems has been a longstanding challenge that requires exquisite control and tuning of mutual particle interactions and appropriate treatment of internal and external degrees of freedom. Here, employing a drastic reduction of the geometrical scaling factor due to the high mass imbalance of Li and Cs atoms, we present the first observation of three consecutive LiCsCs Efimov resonances via three-body recombination rate measurements [1]. The previous analysis of Feshbach resonances [2] is extended with radiofrequency association of LiCs Feshbach molecules to obtain precise mapping of the applied magnetic field onto the scattering length [3]. This new parametrization of Li-Cs interaction properties is used to compare the measured recombination spectra, including Efimov resonance positions and scaling factors, with state-of-the-art few-body theories. These findings are used to elucidate the connection between the universal regime that is excellently approximated by two-body contact interactions and the short-range dominated regime, which is described by the van der Waals tails of pairwise interaction potentials.

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MICROWAVE PUMP-PROBE SPECTROSCOPY IN NV CENTERS

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Negatively charged nitrogen-vacancy (NV^-) color centers in diamonds are intensively studied as promising candidates for fluorescent markers in biological systems, qubits that can be optically initialized and read out, and sensors of magnetic and electric fields. The spectroscopic sensitivity improves when the NV ground-state microwave transitions are narrow, but the transitions suffer from inhomogeneous broadening, especially in high-density NV ensembles. For studying the broadening mechanism in NV centers, we have performed the microwave pump-probe spectroscopy with optical detection [1].

In the CW hole burning experiments, a strong (pump) microwave field drives the $m_S = 0 \leftrightarrow m_S = +1$ transition between the magnetic sublevels of the ground state 3A2, and weak field probes the transition $m_S = 0 \leftrightarrow m_S = -1$ or $+1$. In both cases we observe narrow ($\sim$ 2 MHz) holes within the inhomogeneously broadened resonances ($\sim$ 10 MHz). In the latter case of pumping and probing the same transition, however, additional structures arise from coherent population oscillations. The spectral width of these features is much narrower ($\sim$ 10 kHz), which we attribute to the longer lifetime of the magnetic sublevels populations instead of coherences. Important feature of these narrow resonances is their insensitivity to fluctuations/instabilities of the magnetic field.

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MAGNETOMETRY USING COLD RUBIDIUM ATOMS

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We report on our experiments on nonlinear magneto-optical effects in laser-cooled, near-degenerate rubidium samples. After the loading and cooling, cloud of atoms is released from a Magneto-Optical Trap (MOT). Interaction of atoms with a near- resonant, linearly polarized light leads to an effective creation of long-lived ground-state Zeeman coherences, which is observed through the nonlinear Faraday effect [1] or free induction decay signals of the Larmor precession [2]. Our experiments showed that high rotation angles of a few degrees and coherence lifetimes of a few milliseconds are achieved in mG fields with cold atoms released from MOT in a simple magnetic shielding. Alternatively, with dc field compensation and without the shield, we are able to detect changes in the local magnetic field inside our vacuum system after switching the trap off. The observed signals reveal the contributions from induced eddy currents, as well as, external oscillating fields.

In the next-generation setup, we keep atoms in a far off-resonant optical dipole trap (ODT) inside an improved magnetic shield. The ODT provides long relaxation time and large on-axis optical depth, which result in the improved sensitivity to the magnetic field. Moreover, the tight confinement of atoms enables magnetic field probing with a spatial resolution of a few tens of micrometers.

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STIMULATED RAMAN ADIABATIC PASSAGE IN A QUANTUM SYSTEM COUPLED TO A PLASMONIC NANOPARTICLE

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Recently, there is increasing interest in the study of the interaction of quantum systems (such as atoms, molecules and semiconductor quantum dots) with plasmonic nanostructures. In this work, we present theoretical results on the influence of a spherical metallic nanoparticle to the population transfer in a three-level Λ-type quantum system under conditions for Stimulated Raman Adiabatic Passage. For the study of the systems dynamics, we use the density matrix approach for the quantum system, where the parameters for the electric field amplitudes and the spontaneous decay rates have been calculated using ab initio electromagnetic calculations for the plasmonic nanoparticle. We then present results for the time evolution of the populations of the different levels of the quantum system in both the presence and the absence of the plasmonic nanoparticle. Also, in the presence of the plasmonic nanoparticle, we consider different distances of the quantum system from the plasmonic nanoparticle.

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