Book of Abstracts

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School Lectures

Quantum simulations – an overview

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Classical Information Theory and Cryptography

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Entropy and Quantum Information

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Weak values and related issues

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Introduction to Quantum Computing

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Entanglement in many body systems

Ujjwal Sen
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Recent development on nonlocality and contextuality

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Introduction to quantum metrology

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Uncertainty relations and its applications

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Entanglement Measures

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Quantum communication

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Conference Talks

Multi-fermion quantum walks for distance independent entanglement

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Uncertainty and Speed of Evolution in Presence of Quantum Correlation

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We will introduce a connection between the geometric quantum uncertainty and the speed of quantum evolution on one hand and quantum correlation present in the system on the other. In particular, it will be shown that the time-energy uncertainty relation is bounded below by the geometric measure of multipartite entanglement for an arbitrary quantum evolution of any multipartite system. By analyzing the speed of quantum evolution, we will show that the speed due to local quantum operation of the same system is bounded below by the quantum discords, a quantum correlation measure. The relations are demonstrated for pure as well as for mixed quantum states. We provide examples of physical systems for which the bounds reach close to saturation.

Epistemic States

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Is Quantum Bit Commitment Really Impossible?

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Bell Inequality violation and entanglement in Dirac materials

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Generating electronic entanglement which is easily controllable is the need of the hour from the standpoint of building a quantum computer using novel materials like graphene and topological insulators collectively called Dirac materials. Specially, non local correlations across Dirac materials are calculated with insulators separating a superconducting region. Band structure and relativistic physics gives rise to a rich structure in the states of the electric current flowing across these novel materials. We identified a parametric regime where non-local correlations of the current appear signifying entangled currents, a Bell test on these non-local correlations leads to confirmation of quantum correlations.

Shared purity of multipartite quantum states

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Fidelity plays an important role in measuring distances between pairs of quantum states, of single as well as multiparty systems. Based on the concept of fidelity, we introduce a physical quantity, shared purity, for arbitrary pure or mixed quantum states of shared systems of an arbitrary number of parties in arbitrary dimensions. We find that although it detects a quantum feature of the shared state, it is different from quantum correlations. We prove that a maximal shared purity between two parties excludes any shared purity of these parties with a third party, thus ensuring its quantum nature. Moreover, we show that all generalized GHZ states are monogamous, while all generalized W states are non-monogamous with respect to this measure. We applythe quantity to investigate the quantum XY spin-1/2 models, and observe that it can faithfully detect the quantum phase transition present in these models. We perform a finite-size scaling analysis and find the scaling exponent for this quantity.

Lossy quantum data compression

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Strong subadditivity of von Neumann entropy in Quantum Information

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Strong subadditivity is a key property of von Neumann entropy. We will review some results in quantum information that strong subadditivity leads to. In particular, we will discuss how it leads to estimation of channel capacities, both in the case of a single sender and a single receiver, as well as in the multiport case. We will also discuss how it demonstrates the existence of genuine multiparty entanglement in resonating valence bond states.

Complementarity of Quantum Correlations in Cloning and Deleting of Quantum State

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Minimum error discrimination of linearly independent pure states: analytic properties of optimal POVM

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The optimization conditions for minimum error discrimination of linearly independent pure states comprise of two kinds: stationary conditions over the space of rank-one projective measurements and the global maximization conditions. A discrete number of solutions satisfy the former and of them a unique one will solve the latter. In the case of three linearly independent pure states, we show that the stationary conditions translate to a system of simultaneous polynomial (non-linear) equations in three or more variables thus explaining why it's so difficult to obtain a closed-form solution for the optimal POVM. Additionally, our method suggests that as an ensemble of linearly independent pure states is varied as a differentiable function of some independent parameters the optimal POVM will also vary as a differentiable function of the same parameters. By employing the implicit function theorem, we exploit this fact to obtain a numerical technique for finding the solution of minimum error discrimination for linearly independent pure states by dragging the solution from a known example (say, pure orthogonal states) to any general linearly independent ensemble of pure states on the same Hilbert space.

Generating continuous variable nonclassical states using superposition of number-conserving quantum operations

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We investigate the nonclassical states generated in continuous variable (CV) optical fields on operating it with a number-conserving operator formed by the generalized superposition of products of field annihilation ($\hat{a}$) and creation ($\hat{a}^\dag$) operators, of the type $s\hat{a}\hat{a}^\dag + t\hat{a}^\dag\hat{a}$, with $s^2+t^2=1$. Such an operator is experimentally realizable and can be suitably manipulated to generate nonclassicality. Such nonclassical two-mode states can be used as quantum channels in CV quantum teleportation of single-mode coherent and squeezed states. We show that the teleportation fidelity of highly Einstein-Podolosky-Rosen (EPR) correlated two-mode squeezed states gets enhanced and those of the EPR non-correlated thermal and coherent channels get reduced, thus enhancing quantum fidelity while reducing classical fidelity. The operation could prove useful in efficient implementation of noisy non-Gaussian channels, formed by linear operations, in future teleportation protocols.

Gibbs paradox and quantum information

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This talk will examine the old Gibb's paradox in statistical mechanics in the new light of quantum information to see whether there is any new useful input from quantum information science to the understanding the role of indistinguishability in the statistical physics of many particles.

Quantum Correlations, Spatiotemporal Control and Quantum Information Processing

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We demonstrate experimental quantum correlations and their timescales under different environments using femtosecond laser techniques. We also show how such studies are highly influenced when additional control fields are used. We also demonstrate confinement related quantum correlations due to micro-heterogeneous environments. We propose how such experimentally observed coherent aspects can be useful for quantum information processing.

Linear optics based single-photon-assisted protocol for entanglement concentration in cat state, GHZ-like state and all families of 4-qubit entangled states

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We have prescribed an optical entanglement concentration protocol (ECP) for non-maximally entangled (n+1)-qubit state (α|ψ_0 >|0> + β|ψ_1 |1>)n+1 where |ψ_0> and |ψ_1> are mutually orthogonal n-qubit states. The protocol is based on concentration of entangled state by local actions using single photon and classical communications. The state used in the protocol is a general state which includes cat state, ghz-like state, four qubit state etc of the form α|ψ_0 |0> + β|ψ_1> |1> . It is also shown that specific states from all the 9 different families of 4-qubit entangled states that are not connected by stochastic local quantum operations assisted by classical communication (SLOCC) can be expressed as √1/2 (|ψ_0 |0> + |ψ_1> |1>) for specific choices of the parameters that defne a family of 4-qubit entangled states. This state is vastly used for quantum communication protocols. Compared with other entanglement concentration protocols, we do not need to know the accurate coeffcients of the initial state. Proposed protocol needs less operations and classical communications. It is shown that the protocol can be implemented using linear optics thus it is realizable in current technology

Local realism, macrorealism and non-contextuality: An unified approach.

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Prospect of using single photons propagating through Rydberg EIT medium for quantum computation

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Electromagnetically induced transparency of a probe beam can be observed in the presence of a strong beam coupled to the Rydberg state. Due to strong interactions between the atoms in the Rydberg state, Rydberg EIT medium is expected to offer large Kerr non-linearity of the probe photons which can be used for quantum computation. In this talk, I will discuss our experimental progress towards the measurement of the Kerr non-linearity of Rydberg EIT in thermal rubidium vapor.

Which-way experiment with internal degrees of freedom

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Thermodynamics of Quantum Preparations

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The second law of thermodynamics informs us of the connection between heat and entropy generated during a process. This law is the consequence of the structure of completely positive trace preserving (CPTP) maps in the quantum regime. Such maps describe evolution of system dynamics when the system is initially uncorrelated with its environment. We generalize the second law of thermodynamics in the presence of initial correlations of the system and environment, where CPTP maps no longer describe system dynamics. In the presence of such correlations, the operationally correct procedure involves quantum preparations that conditionally affect the state of the environment. We will discuss this generalized second law and present an application to unital memoryless maps.

Decoherence-Free/Noiseless Qudits in Quantum Information Processing

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Decoherence-free, or noiseless subsystems, (DNS) have found a variety of applications in quantum computing and quantum information. Decoherence-free/Noiseless subsystems have been shown to remove collective errors from quantum systems. However, a more important application is to enable universal quantum computing on a subspace of the Hilbert space when it is not possible on the entire Hilbert space. They can also be used to enable communication between parties that do not share a reference frame. After a brief introduction to DNS, these applications will be discussed.

Secure quantum communication beyond QKD

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Upper Bound on Singlet Fraction of Mixed Entangled Two Qubit

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Whirling waves in Interference experiments

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Hardy's argument for contextuality

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Classical mechanics and 'extreme' quantum mechanics

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This is an attempt to examine issues of quantum measurement and quantum to classical transition from the point of view of treating classicality as quantum mechanics of large number of particles, keeping entanglement and superposition intact, without phenomena like decoherence or the usual approximation of treating 'apparatus' as fully classical. Perhaps the macroscopic world is perceived as classical because it is highly quantum mechanical!

Quantum Teleportation

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Nonlocality under biased scenario

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Quantum correlations and work extraction

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As shown recently [Hovhannisyan et al., PRL 111, 240401 (2013)], given a set of identical quantum systems, optimal work extraction can be achieved without generating entanglement during the process, even if a factorized dynamics is in general slower than an entangled one, given that a larger number of steps is required. In this talk, I will show that optimal work extraction necessarily requires the generation of quantum discord. Genuine multipartite quantum correlations are necessary for fast extracting operations, while slower paths are accompanied by the presence of subsystem-localized discord. I will also show that the largest the amount of work that can be extracted from the initial state, the more discord is produced during the dynamics.

From Leggett-Garg Inequality to Secure Quantum Key Distribution

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Perhaps the most important application of quantum information theory lies in quantum cryptography. Pioneered by protocols known as BB84 and E91 , their intuitive security was later made more rigorous and they have also been experimentally realized. A recent development has been the notion of device-independent (DI) quantum cryptography, which arose because of the observation that though quantum cryptography is guaranteed by the laws of quantum physics to be unconditionally secure, still it can be rendered insecure by flaws in the practical realization, which may be exploited by a malicious eavesdropper, who could potentially be the vendor. In DI quantum cryptography, the devices used are not assumed to be trusted and well-characterized. Instead Alice and Bob must convince themselves of security of the protocol simply by running though a series of statistical tests, without having to consider the detailed inner workings of the devices. Here a key role played by Bell-type inequality (BI), so that protocols in the DI scenario necessarily involve entanglement. A sufficiently large violation of BI guarantees security against Eve, who may be a general non-signaling agent. Various works have studied DI security by empowering Eve to various degrees (from a single-qubit attack to beyond). Against this backdrop, it may noted that most practical cryptographic protocols are of the prepare-and-measure kind (where Alice prepares and transmits a state to Bob, who measures it), rather than entanglement-based. As full device-independence is not possible in this case, semi-device-independence, a weakening of DI requirement, has been proposed here. In the semi-DI scenario, devices are uncharacterized, but all quantum states involved are of bounded-dimension. Here we consider a complementary scenario for BB84, allowing unbounded dimension, but no state emissions, i.e., any states emitted are outside the DI scenario, but not all key bits are required to be generated by state emissions, and these are subject to an attack in the DI scenario. One motivatation here was to explore in the context of quantum cryptography, the possibility of an application of the temporal analogue of BI, known as the Leggett-Garg inequality (LGI), which is violated by the relevant quantum mechanical results for the sequential measurements of a suitable observable on the same particle. The second motivation was to explore the minimal modification of BB84 that would protect it against the type of attack specified by Acin et al.. We propose two such schemes, in one of which, both key generation and security are ensured by using LGI, while for the other, secret bit generation is done by using the BB84 scheme, whereas for the security check, an additional basis is introduced while invoking an appropriate test based on LGI.

Local unitary equivent classes of symmetric N-qubit mixed states

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Genuine multiparty quantum entanglement suppresses multiport classical information transmission

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Quantum correlations in multipartite systems form a central focus of contemporary quantum information science. This is due to the fact that quantum correlation is the fundamental resource for implementing several quantum communication protocols. In this talk, I will discuss about a quantum information protocol to transmit classical information, and its relationship with multipartite quantum correlation. I will start with establishing a universal complementarity relation between the capacity of classical information transmission by employing a multiparty quantum state as a multiport quantum channel, and the corresponding genuine multipartite entanglement measures. Similar complementary relations are established by considering the quantum correlation measures like tangle and discord monogamy score. By doing so, we identify the maximally dense-coding-capable quantum states which have the maximal multiport dense coding capacity among all three-qubit pure states with an arbitrary fixed amount of the multiparty quantum correlations.

Orbital angular momentum of light: Applications in quantum information

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Do Large Number of Parties Enforce Monogamy in All Quantum Correlations?

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Monogamy is a non-classical property that restricts the sharability of quantum correlation among the constituents of a multipartite quantum system. Quantum correlations may satisfy or violate monogamy for quantum states. Squares of the concurrence and the negativity are monogamous while entanglement of formation, quantum discord, quantum work-deficit are known to violate monogamy for three-qubit pure states. We provide evidence that almost all pure quantum states of systems consisting of a large number of subsystems are monogamous with respect to all quantum correlation measures of both the entanglement-separability and the information-theoretic paradigms, indicating that the volume of the monogamous pure quantum states increases with an increasing number of parties. Nonetheless, we identify important classes of pure states that remain non-monogamous with respect to quantum discord and quantum work-deficit, irrespective of the number of qubits. We find conditions for which a given quantum correlation measure satisfies vis-a-vis violates monogamy.

Understanding Ghost Interference

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We theoretically analyze the ghost interference experiment, carried out with entangled photons. It is argued that the experiment is intimately connected to a double-slit interference experiment where, which-path information exists. The reason for not observing first order interference behind the double-slit, is clarified. It is shown that the underlying mechanism for the appearance of ghost interference is, the more familiar, quantum erasure. Recently performed two-color ghost interference experiment is also analyzed and some interesting predictions are made.

TBA

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Distribution of quantum correlations in Heisenberg spin systems

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The distribution of quantum correlation present between different parts of a system, is investigated for spin systems. For a pair of spins in a many-spin ground state, we study the diagonal and off-diagonal spin? spin correlation functions and the local magnetization. These spin functions determine the quantum correlation measures, like pair-wise concurrence, quantum discord and other measures of quantum information. We show that for isotropic and translationally invariant states, the quantum correlations depend only on the diagonal spin correlation function. The pair concurrence shows a strict short-ranged behaviour. The quantum discord displays a long-range behaviour. We will discuss the distribution of quantum correlations among various pairs of the many-spin system, for an anisotropic Heisenberg spin chain which shows a Kosterlitz-type quantum critical behaviour as the anisotropy is varied. The preferred measurement basis for the minimum conditional entropy, which determines the discord, changes discontinuously across the critical point. We will also discuss the distribution of conditional entropies as the measurement basis is varied. For the isotropic model, the conditional entropy distribution is a delta-function, whereas it has a twin-peak structure for the anisotropic model. It is shown that the average value and the mean-square fluctuation of the conditional entropy also show a signature of the critical-point behaviour.

Einstein's recoiling slit experiment, complementarity and uncertainty

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Device-independent quantum key distribution based on Hardy's paradox

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In this paper, we present a secure device-independent quantum key distribution scheme based on Hardy's paradox. It has several novel, in comparison with protocols based on Bell inequalities, features: (a) The bits used for secret key do not come from the results of the measurements on an entangled state but from the choices of settings which are harder for an eavesdropper to influence; (b) Instead of a single security parameter (a violation of some Bell inequality) a set of them is used to estimate the level of trust in the secrecy of the key. This further restricts the eavesdropper's options. We prove the security of our protocol in both ideal and noisy case.

Bell theorem as the key for Bit Commitment

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Posters

Effectiveness of Depolarizing noise in causing sudden death of entanglement

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In view of the recent observation that depolarizing noise is more effective in causing sudden death of entanglement in two-qubit states , we carry out a study to establish this fact even in qubit-qutrit and qutrit-qutrit systems. Considering a maximally entangled pure state of a qubit-qutrit , we examine the sudden death of entanglement due to the action of noise on only one part of the state, either qubit or qutrit. The noise models that we consider are amplitude noise, phase noise depolarizing noise and generalized amplitude noise (GAD). We show that while amplitude, phase noise lead to asymptotic decay of entanglement, depolarizing and Generalized amplitude damping cause sudden death of entanglement in these states. The disentanglement times due to depolarizing noise is found to be shorter than that due to Generalized amplitude damping, thus proving that depolarizing noise is more effective in causing sudden death of entanglement compared to other noises. We carry out a similar analysis for maximally entangled pure qutrit-qutrit systems and arrive at the same conclusion. We employ negativity of partial transpose as the measure of entanglement in both qubit-qutrit and qutrit-qutrit cases.

Almost all multipartite pure states are monogamous for all quantum correlation measures in large quantum systems

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Monogamy is a non-classical property that restricts the sharability of the quantum correlation among the constituents of a multipartite quantum system. Quantum correlations may satisfy or violate monogamy for different quantum states. Here we provide evidence that almost all pure quantum states of systems consisting of a large number of subsystems are monogamous with respect to all quantum correlations of both the entanglement-separability and the information-theoretic paradigms. Put differently, the volume of the monogamous quantum states increases with an increasing number of parties. Nonetheless, we identify an important class of pure states, namely the Dicke states, that remain non-monogamous with respect to quantum discord and quantum work-deficit, irrespective of the number of qubits. We identify conditions for which a given quantum correlation measure satisfies vis-a-vis violates monogamy.

Quantum discord with Weak Measurements

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Weak measurements cause small change to quantum states, thereby opening up the possibility of new ways of manipulating and controlling quantum systems. We ask, can weak measurements reveal more quantum correlation in a composite quantum state? We prove that the weak measurement induced quantum discord, called as the "super quantum discord", is always larger than the quantum discord captured by the strong measurement. Moreover, we prove the monotonicity of the super quantum discord as a function of the measurement strength. We find that unlike the normal quantum discord, for pure entangled states, the super quantum discord can exceed the quantum entanglement. Our result shows that the notion of quantum correlation is not only observer dependent but also depends on how weakly one perturbs the composite system.

Quantum Speed-Limit for Mixed States with a New Metric

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The minimal evolution time for a system between two different states is an important notion for developing ultra-speed quantum computer and communication channel.
An experimentally realizable operation dependent metric on quantum state space is introduced. We show the condition for our metric distance between two states to be gauge invariant. Lower bound of the evolution time of a system is studied for any arbitrary process using this metric.

Multipartite Dense Coding vs. Quantum Correlation: Noise Inverts Relative Capability of Information Transfer

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A highly entangled bipartite quantum state is more advantageous for quantum dense coding protocol than states with low entanglement. Such a correspondence, however, does not hold even for pure quantum states in a multipartite domain. We establish a connection between the multiparty capacity of classical information transmission and several multipartite quantum correlation measures. In particular, we show that for the noiseless channel, if multipartite quantum correlations of an arbitrary multipartite state of arbitrary number of parties is the same as that of the corresponding generalized Greenberger-Horne-Zeilinger (GGHZ) state, then the multipartite dense coding capability of former is the same or better than that of the GGHZ state. Interestingly, in a noisy channel scenario, where we consider both uncorrelated and correlated noise models, the relative abilities of the quantum channels to transfer classical information can get inverted by administering a sufficient amount of noise. For the case of noiseless channels, when the shared state is an arbitrary mixed state, we also make a link between the classical capacity and multipartite quantum correlation measures.

The counterfactual paradigm in quantum cryptography

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It is a conventional assumption in physics that physical particles must travel between two points for information to travel between them. Counterfactual cryptography involves a secret bit being generated without the physical transmission of a particle [1-4], and is based on the idea of interaction-free measurement [5]. The counterfactual key generation may be realized either via a "chained" quantum Zeno effect [6] or a Mach-Zehnder interferometer [7] or a Michelson interferometer with or without polarization encoding. We propose other crypto-tasks besides quantum key distribution (QKD) for which the counterfactual paradigm may be put to use. In a quantum optical treatment, the single-particle superposition that appears in counterfactual QKD is represented by vacuum-particle entanglement. We may consider equivalent, non-counterfactual protocols where this is replaced by conventional inter-particle entanglement. We compare and contrast the performance, security and efficiency of these two classes of cryptographic protocols.

A study of Quantum Correlation for Three Qubit States under the effect of quantum Noisy Channels

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We study the dynamics of Quantum Dissension for three qubit states in various dissipative channels such as amplitude damping, dephasing, depolarizing etc. Our study is solely based on Markovian environments where quantum channels are without memory and each qubit is coupled to its own environment. We start with mixed GHZ, mixed W, mixture of separable states, a mixed biseparable state, output density matrix of DQC1 architecture as the initial states and observe that the decay of quantum dissension is asymptotic in contrast to sudden death of quantum entanglement in similar environments. Hence, quantum correlation in general is more robust against the effect of noise. However, for a given class of initial mixed states, we find a temporary leap in quantum dissension for a certain interval of time. More precisely, we observe the revival of quantum correlation to happen for certain time period. This is a signature of the fact that the nature of quantum correlation (quantum disco! rd, quantum dissension) defined from the information theoretic perspective is radically different from the correlation (quantum entanglement) defined from the enatnglement-separability paradigm and can increase under the effect of the local noise. We also study the effects of these channels on the monogamy score of each of these initial states. Interestingly, we find that for certain class of states and channels, there is change from negative values to positive values of the monogamy score with classical randomness as well as with time. This gives us an important insight in obtaining states which are freely sharable (polygamous state) from the states which are not freely sharable (monogamous).

Constructive Interference Between Disordered Couplings Enhances Multiparty Entanglement in Quantum Heisenberg Spin Models

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Disorder appears almost inevitably in most systems -- due to the presence of impurities, dislocations of atoms from their regular lattice sites, and environmental effects on the system. Studying quantum correlations, both bipartite and multipartite, in such systems is of interest in recent times, owing to their usefulness in realizing many quantum information protocols. We have analysed the behaviour of quantum correlations in many-body systems like quantum XY and XYZ spin models where disorder is present, in the couplings and fields of the corresponding Hamiltonian, as well as a non-zero bath temperature. ``Local disorder'' is introduced in the nearest neighbour interactions and fields for such models, and at the same time, ``global disorder'', in the form of temperature, is also introduced for the different models. We find that for various choices of system parameters, quantum as well as classical correlations get enhanced in disordered systems as compared to those in the ordered ones. Moreover, in the case of the XYZ model, we point to a situation in which in the presence of disorder in different types of couplings enhances a multipartite quantum correlation, while the same is absent when the disorders are applied individually.

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The Schr\"odinger cat state plays a crucial role in quantum theory, and has important fundamental as well as technological implications, ranging from quantum measurement theory to quantum computers. The power of the potential implications of the cat state lies in the quantum coherence, as measured by the degree of entanglement, between its microscopic and macroscopic sectors. We show that in contrast to other cat states, it is possible to choose the states of the macroscopic sector in a way that the resulting cat state, which we term as the W-cat state, has quantum coherence that is resistant to the twin effects of environmental noise -- local decoherence on all the particles and loss of a finite fraction of its particles. The states of the macroscopic sector of the W-cat state are macroscopically distinct in terms of their violation of Bell inequality.

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The conditional form of the `sandwiched??? quantum relative Tsallis entropy is made use of in identifying entanglement beyond the methods based on global and local spectra of composite quantum states. Separability range in one parameter family of W and GHZ states with 3 and 4 qubits is explored using this criteria and the results inferred from negative Tsallis conditional entropy matches with that obtained through Peres??? partial transpose criteria for one-parameter family of W states, in one of its partitions. The criteria is shown to be non-spectral through its usefulness in identifying entanglement in isospectral density matrices.

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