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Chapter 1 : Quantum Information with Continuous Variables - Ebook pdf and epub

Abstract: Quantum information is a rapidly advancing area of interdisciplinary research. It may lead to real-world applications for communication and computation unavailable without the exploitation of quantum properties such as nonorthogonality or entanglement.

Quantum information[edit] Quantum information differs strongly from classical information, epitomized by the bit , in many striking and unfamiliar ways. Among these are the following: A unit of quantum information is the qubit. Unlike classical digital states which are discrete , a qubit is continuous-valued, describable by a direction on the Bloch sphere. Despite being continuously valued in this way, a qubit is the smallest possible unit of quantum information, as despite the qubit state being continuously-valued, it is impossible to measure the value precisely. A qubit cannot be wholly converted into classical bits; that is, it cannot be "read". This is the no-teleportation theorem. Despite the awkwardly-named no-teleportation theorem, qubits can be moved from one physical particle to another, by means of quantum teleportation. That is, qubits can be transported, independently of the underlying physical particle. An arbitrary qubit can neither be copied, nor destroyed. This is the content of the no cloning theorem and the no-deleting theorem. Although a single qubit can be transported from place to place e. Qubits can be changed, by applying linear transformations or quantum gates to them, to alter their state. While classical gates correspond to the familiar operations of Boolean logic , quantum gates are physical unitary operators that in the case of qubits correspond to rotations of the Bloch sphere. Due to the volatility of quantum systems and the impossibility of copying states, the storing of quantum information is much more difficult than storing classical information. Nevertheless, with the use of quantum error correction quantum information can still be reliably stored in principle. The existence of quantum error correcting codes has also led to the possibility of fault tolerant quantum computation. Classical bits can be encoded into and subsequently retrieved from configurations of qubits, through the use of quantum gates. By itself, a single qubit can convey no more than one bit of accessible classical information about its preparation. However, in superdense coding a sender, by acting on one of two entangled qubits, can convey two bits of accessible information about their joint state to a receiver. Quantum information can be moved about, in a quantum channel , analogous to the concept of a classical communications channel. Quantum messages have a finite size, measured in qubits; quantum channels have a finite channel capacity , measured in qubits per second. Quantum information, and changes in quantum information, can be quantitatively measured by using an analogue of Shannon entropy , called the von Neumann entropy.

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Chapter 2 : [quant-ph/] Quantum information with continuous variables

Quantum information may sound like science fiction but is, in fact, an active and extremely promising area of research, with a big dream: to build a quantum computer capable of solving problems that a classical computer could not even begin to handle. Research in quantum information science is now.

That is, the quantum system uses a set of two discrete states designated a logical one and a logical zero. Quantumness is included by creating superpositions of the two statesâ€”a superposition places a quantum system in both states simultaneously to form a qubitâ€”and by entangling different qubits together. In a classical system, this would involve something like a continuously varying voltage or current. In a quantum system, something like phase could be used. The phaseâ€”essentially the relationship of wavefronts between different wavesâ€—is a quantum property that can be put into a superposition state, and two different continuous variable qubits can be entangled. Because, apart from noting its existence and doing a bit of theoretical work on it, physicists have largely ignored continuous variable quantum systems. But in the last few weeks, physicists have finally shown continuous variable quantum computation a bit of love, with a number of experimental papers having come out. So, why might you want to use continuous variable qubits? The main advantage is that they can naturally be stored in a quantum state that is shared by many particles. Their work allows the creation of entangled beams of photonsâ€”not individual photons entangled with each other, but rather the statistical properties of groups of photons. In their case, the entanglement was between the amplitude e. They did this by copying what physicists had been doing to create a source of squeezed single photon pairs. As we recently described it, the amplitude and phase have a certain intrinsic noise that is governed by the Heisenberg uncertainty principle, so there is a joint minimum noise. You can, with difficulty, create a situation where the noise in the amplitude is much less than the joint minimum, while the noise in the phase is much greater or vice versa. The result is called squeezed light. In addition to building a traditional squeezer, they added two variations. Second, instead of creating two photons with the same wavelength, they created two streams of photons with very different wavelengths. When carefully analyzed, the photon sources were found to be not just squeezed but also entangled. Since phase and amplitude can vary continuously, this represents entanglement of a continuous variable qubit. I must admit, though, that I am a bit annoyed by this result. You see, our lab and others have been playing with these devices for years for other purposes, and, every now and again we asked ourselves if the two beams are entangled or squeezed. Yes, that is the sound of incompetence you hear. Controlled superposition In a similar vein, a group of researchers at the National Institute of Information and Communications Technology in Japan have just published a paper in Physical Review Letters where they also show that they can create continuous variable qubits. Like the Chinese group, these researchers also used squeezed light to create their qubits. More importantly, they took the next step. To take advantage of a qubit, you have to be able to place it in an arbitrary superposition state. Essentially, a measurement will give you a valueâ€”the phase is 0. This mixed beam is then shone on a photodiode that clicks occasionally. The click can derive from two sources: Varying the intensity of the laser light changes the weighting of the chance that the click came from the squeezer or from the laser light. Although the team did not present any logic operations, they did demonstrate that they could initialize their qubit with high fidelity to any superposition state that they wanted and then collapse that superposition state with a measurement. Essentially, the first step in the process of creating a logic system: Correcting for data loss Finally, a Nature Photonics paper discusses the advantages of using continuous variable qubits to enable error correction for quantum communications systems. As mentioned above, a critical problem in quantum systems is that, if information is stored in single photons, then photons that are absorbed in transit represent lost information. The solution is to build in redundancy so that lost information can be reconstructed. In yet another use for squeezed light, a multinational team of researchers show how to use it to correct for the absorption of qubits. The process starts by entangling two sources of squeezed light. These entangled beams are then entangled with the optical information being transmitted and a laser beam. This creates four beams of light that are all entangled with one another, sent along four different paths to a receiver. Loss can occur in any of the four paths. The receiver makes measurements by combining pairs of beams at beam splitters in various ways and performing three operations. One measures the degree of squeezing transmitted over the channel, while the other two extract the transmitted information. The shape of the squeezing curve reveals photon loss, allowing what the researchers call a "linear displacement of the phase and amplitude. This recovers a near perfect squeezed light measurement. But, there remains a problem: This allows for two solutions. But, you can only correct one erasureâ€”more than that and you begin to lose information. To avoid this problem, the researchers developed a probabilistic correction algorithm, allowing them to correct for multiple erasures. With these three papers, continuous variable quantum information technology is starting to look interesting. I would note that, like its classical counterpart known as analog computers , there are some advantages to continuous variable quantum computingâ€”some operations look a lot simpler. But, implementation has always been the stumbling block for continuous variable quantum computing, and that may still turn out to be true.

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Chapter 3 : Quantum information - Wikipedia

Continuous-variable quantum information is the area of quantum information science that makes use of physical observables, like the strength of an electromagnetic field, whose numerical values belong to continuous intervals.

Diffusive dynamics and continuous monitoring Section IV Correlations Entanglement of continuous variable systems Section V Technologies Quantum information protocols with continuous variables A grand tour of continuous variable platforms Appendices Some notable facts about the symplectic group The Wiener process Selected mathematical lore on quantum channels Classical and quantum Cramer Rao bounds Author s Bio Alessio Serafini earned his PhD from the University of Salerno. He is currently a Reader at University College London. His research focuses mainly on quantum optics, quantum information with continuous variables, and the theory of quantum control. Reviews "The book is well written. It consists of several problems which are frequently encountered by researchers. Endnotes after each chapter and appendices gives better clarity. The book has given an accessible and self contained introduction to quantum information theory of continuous variable as well as its applications. This bookâ€¦presents the theory of continuous variable quantum systems based on the theory of Gaussian states including operations, dynamics, Hilbert space, phase descriptions, the Gaussian additivity conjecture, entanglement theory, and non-Gaussian manipulations , and shows its applications to experimental platforms, entanglement generation, quantum teleportation, classical channel capacities, quantum metrology, quantum key distribution, and other quantum information and quantum technologies. The idea is to explain the physics subjects using a unifying mathematical approach, but without too many mathematical details. This book is a graduate-level textbook, with 5 parts containing 9 chapters and 70 problems and their solutionsâ€¦This good book is recommended for mathematicians, physicists, philosophers of physics, researchers, and advanced students in mathematics and physics, as well as readers with interest in applications and experiments in this field. Dediu in Mathematical Reviews June "For many years, I have been hoping for a textbook that would systematically and pedagogically cover the topic of Gaussian states and channels in quantum information. This research topic has been one of the core topics in quantum information, given that experimental physicists can prepare such quantum states in the laboratory and many relevant communication channels are described by the Gaussian formalism. Serafini has masterfully assembled such a textbook, drawing on a wealth of experience from teaching the topic to diverse audiences. I deeply appreciate the many detailed derivations in Dr. For the past few months, I have found myself continually accessing Dr. Wilde, Department of Physics and Astronomy, Center for Computation and Technology, Louisiana State University "This book provides a comprehensive introduction to the world of systems with quantum continuous variables, exploring a variety of topics from their foundations to applications. The applications section contains methods of quantum continuous-time monitoring, feedback control, teleportation, secure communication, metrology, and key distribution, which all play fundamental roles in quantum information science. A notable feature of this book is that Gaussian systems are examined thoroughly, enabling the reader to conduct straightforward calculations and obtain analytic results. Another strength is that a wealth of exercise problems are provided, together with detailed answers. This is a well-organized introduction to cutting-edge quantum information science and can also be used as a textbook to deepen understanding of quantum mechanics. I would definitely recommend this book to students, in addition to researchers who are interested in quantum physics and quantum information science. In fact quite some years ago, together with colleagues, we tried. But writing a book, and especially writing it well, is an enormous task and in the end we failed to come anywhere near completion. But I always felt that there was a need for a book on continuous variables which are so important in quantum information science and especially quantum communication. Hence, I am all the more delighted to see that Alessio Serafini showed more resolve than we did then and wrote such an excellent textbook on continuous variable physics that is bringing together all the most important concepts and technical tools of this area. Finally I can stop handing out our half-written book to my students and postdocs and just give them Quantum Continuous Variables which, I am sure, will become the standard reference on the topic. The book goes through the basics in a rigorous yet easy to follow fashion, and covers even the latest developments in quantum information theory with continuous variable systems. I particularly like the part about Gaussian channels, containing new elegant proofs of seminal results which are very hard to track elsewhere. The book also includes a gallery of physical realizations of Gaussian states and operations in different quantum technology platforms. In general, the author writes in a compelling style which will no doubt result in a highly popular and accessible textbook. I have been awaiting such a book for at least ten years, and will eagerly recommend it to all my current and future students!

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Chapter 4 : Continuous-variable quantum information - Wikipedia

quantum information based on continuous quantum variables, with emphasis on quantum optical implementations in terms of the quadrature amplitudes of the electromagnetic ï¬•eld. CONTENTS.

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Chapter 5 : Continuous quantum variables for computing, communications | Ars Technica

Quantum information may sound like science fiction but is, in fact, an active and extremely promising area of research, with a big dream: to build a quantum computer capable of solving problems that a classical computer could not even begin to handle.

Implementation[edit] One approach to implementing continuous-variable quantum information protocols in the laboratory is through the techniques of quantum optics. These observables establish a phase space on which Wigner quasiprobability distributions can be defined. Quantum measurements on such a system can be performed using homodyne and heterodyne detectors. Quantum teleportation of continuous-variable quantum information was achieved by optical methods in Braunstein in , was in the tradition of the circuit model: An algorithm might be described in the language of quantum mechanics, but upon closer analysis, revealed to be implementable using only classical resources. Such an algorithm would not be taking full advantage of the extra possibilities made available by quantum physics. In the theory of quantum computation using finite-dimensional Hilbert spaces, the Gottesmanâ€"Knill theorem demonstrates that there exists a set of quantum processes that can be emulated efficiently on a classical computer. Generalizing this theorem to the continuous-variable case, it can be shown that, likewise, a class of continuous-variable quantum computations can be simulated using only classical analog computations. This class includes, in fact, some computational tasks that use quantum entanglement. A major motivation for investigating the quantum computation of continuous functions is that many scientific problems have mathematical formulations in terms of continuous quantities. The computational complexity of a problem can be quantified in terms of the minimal computational resources necessary to solve it. In quantum computing, resources include the number of qubits available to a computer and the number of queries that can be made to that computer. The classical complexity of many continuous problems is known. Therefore, when the quantum complexity of these problems is obtained, the question as to whether quantum computers are more powerful than classical can be answered. Furthermore, the degree of the improvement can be quantified. In contrast, the complexity of discrete problems is typically unknown. For example, the classical complexity of integer factorization is unknown. One example of a scientific problem that is naturally expressed in continuous terms is path integration. The general technique of path integration has numerous applications including quantum mechanics , quantum chemistry , statistical mechanics , and computational finance. Because randomness is present throughout quantum theory, one typically requires that a quantum computational procedure yield the correct answer, not with certainty, but with high probability. One also specifies a degree of uncertainty, typically by setting the maximum acceptable error.

Chapter 6 : Quantum Continuous Variables: A Primer of Theoretical Methods - CRC Press Book

Continuous variable (CV) systems are systems in which the relevant degrees of freedom are continuous variables. With respect to those degrees of freedom, the quantum states of continuous.