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Chapter 1 : Quantum information - Wikipedia

The Physics of Quantum Information is essential reading for anyone new to the field, particularly if they enter from the direction of quantum optics and atomic physics." Gerard J. Milburn, Australia; Quantum Information and Computation 1, ().

For several decades, physicists focused on applying the equations, while generally ignoring questions about interpreting the equations. This resulted in the development of invaluable quantum-based technologies, including transistors and modern electronics. However, in recent years there has been increasing interest in attempting to understand the nature of reality indicated by these equations. This understanding may be important for developing new technologies such as quantum computing. The primary equation of quantum physics is in the form of waves that include terms for every potential or possible outcome of an experiment or observation. However, there is intrinsic variability and uncertainty on the quantum level and the waves indicate only the probability that a given outcome will occur. The equations do not deterministically specify which outcome will actually be found. The actual outcome that manifests appears to be random. The waves are described as probability waves, and the equation is called the wave function. There is no known medium or substance for the waves. Taken at face value, the wave function indicates that the most realistic description of the state of a particle prior to observation is a combination of all the potential outcomes for the observation. The most well known is the double slit experiment, which indicates that an unobserved individual particle sent toward two slits in a screen responds to both slits. The particle behaves as if it were a wave that is spread over space and that passes through both slits, rather than as a discrete particle passing through only one of the slits. The experimental results display interference patterns that are exactly in accordance with the wave function. The combination of possible or potential outcomes in a wave function is called a superposition. Two particles become entangled when the wave functions have interaction terms that make the state of one particle related to the state of the other particle. The two particles must be considered as a unitary system. A particle that is not entangled can be completely described with a wave function that does not include terms referring to another particle. The entanglement is nonlocal because the two particles may become widely separated in space, but somehow remain connected. The outcome of a measurement for one particle cannot be predicted, but a measurement of the other particle will always find the expected relationship. A measurement appears to apply to the entangled particles as a unit. Nonlocal entanglement has been verified empirically. The randomness of the outcome that is found with a measurement means entanglement cannot be used to directly transmit useful information between different locations. Entanglement can also occur between a particle and a larger system or the environment. Both involve symbols of potential conditions rather than symbols of existing tangible reality. In both cases, the manifestation of one of the potential outcomes can be viewed as information creation. However, the concepts of media and interpretational infrastructure are clearly applicable for human imagination, but are of doubtful applicability for quantum processes. The system can be in a superposition of possible outcomes prior to measurement. The act of measurement or observation transforms the state of the system from the superposition to a single outcome state consistent with classical physics. This is known as the measurement problem and is subsumed by the newer term quantum-to-classical transition. The wave function predicts that when a particle interacts with a measurement apparatus the particle and apparatus may become an entangled superposition. The wave function does not predict a transformation into one outcome. At present there is not a scientific consensus for conceptualizing the probability waves or for understanding how observed physical reality emerges from them. Several ideas have been proposed for addressing this measurement problem, but none have convincing support. The key concepts of the theories that have received the most attention are briefly summarized below. The historical development and numerous refinements and criticisms of these theories are beyond the scope of the present discussion. Similarly, other lesser-known theories are not discussed. One notable philosophical difference among the proposed interpretations is the role of mathematical equations. Some physicists view the equations of quantum physics, and perhaps physics in general, as abstract models that can be used to make predictions, but that should not be associated with concepts about mechanisms or the nature of reality. On the other hand, others view the concepts about mechanism and the nature of reality as import in working with the equations, and particularly in developing increased scientific understanding. Orthodox or Standard Interpretation The orthodox or standard interpretation presented in most past textbooks on quantum physics postulates that the act of measurement causes a discontinuous collapse or reduction of the wave function from a state of superposition to one observed outcome Schlosshauer, , pp. There is no explanation of the nature of the collapse or the act of measurement. This interpretation generally takes the position that the equations are useful only for making predictions and that it is not appropriate to try to conceptualize the properties of quantum phenomena prior to measurement. Copenhagen Interpretation The closely related Copenhagen interpretation adds the postulate that the wave function collapse occurs when a quantum system interacts with a macroscopic measurement apparatus Schlosshauer, , pp. In this dualistic worldview, the realm of classical physics does not emerge from the quantum level, rather the macroscopic realm is the primary reality and the quantum level is secondary. This interpretation implicitly focuses on measurements or observations by humans and treats other situations as not knowable. External Observer Interpretation The external observer interpretation proposes that the wave function collapse occurs when a measurement result comes into the consciousness or mind of an observer Schlosshauer, , pp. This interpretation derives from the fact that an observer finds a specific outcome, but the wave function does not describe or predict a collapse to a single state. The transition from a quantum superposition to a discrete classical state is placed at the last step in the process of measurement and observation. This dualistic interpretation distinguishes consciousness from physical matter and has a long and varied history. Some authors argue that it is implied in the orthodox and Copenhagen interpretations. Observers happen to find themselves in a particular world, and are not aware that there are other worlds with different outcomes and counterparts of themselves. This interpretation assumes each possible outcome in the wave function fully represents a parallel reality. This interpretation does not require unexplained collapses or observers that are not part of the wave function, but it does require a continuous, infinite splitting of the world. Many-minds interpretations apply the splitting to the consciousness of observers rather than to the physical world. The wave function is irreversibly reduced when the location of a particle is registered on a macroscopic or classical level, such as with an experimental apparatus. This model gives results identical to traditional quantum physics in most situations, and the cases with predicted differences cannot yet be empirically tested. Bohmian mechanics has received relatively little attentionâ€”perhaps because it cannot be empirically distinguished from other interpretations and the practical value of the additional complexity is questionable. Concepts of information are increasingly viewed as a central factor in quantum physics. Recent studies have investigated what constitutes a measurement that causes the quantum-to-classical transition. For a traditional double slit experiment, it has long been known that adding a detector to determine if the particle passed through a certain one of the slits will eliminate the quantum superposition. Experiments have investigated different methods for obtaining this which-path information or which-way information. If plates that alter light polarization are placed in front of the slits, the photons from the different slits will have different polarizations that could be detected by an appropriate device to indicate which slit a photon passed through. The presence of the polarizing plates eliminates the quantum superposition and associated interference pattern. Note that the light polarization indicates the path of the particle and is physical information as defined here, but an actual symbolic representation with interpretational infrastructure as occurs with a formal measurement is apparently not necessary. When partial information is obtained about the path of a particle, the resulting interference patterns are weaker, but still present. The interference patterns fade out and the results become classical as more information is obtained about the path of the particle. Time Independence In other experiments, the decision as to whether to use a which-path device is made after the particle has presumably passed through the slits. The quantum-to-classical results of these delayed choice experiments are the same whether the decision is made before or after the particle should have passed through the slit s Greene, , pp. Such results are incomprehensible in terms of classical physics and traditional scientific determinism. If photon A has two possible paths and photon B has possible states that are entangled with the path of photon A, then the which-path information for photon A can be obtained by observing photon B. Once photon A becomes entangled with photon B in a way that depends on the path of photon A, photon A will not show superposition or interference patterns if it is examined alone. This is true even if photon B is not observed by a person. However, if the two photons are examined together with a coincidence detector, an interference pattern can be seen in the relationship between the particles that cannot be found with either particle individually. These results have been found in various experiments e. If these results were not true, it would be possible to transmit information across unlimited distances from photon B to photon A by the timing of when the superposition and interference pattern for photon A collapsed due to observation of photon B. However, quantum entanglement apparently cannot be used for this type of transfer of useful information. Some type of classical interaction between A and B is always needed to decode the entangled information. The fact that which-path entanglement causes quantum superpositions to disappear for the individual entangled particles or systems has important implications and is the foundation of decoherence. The initial theoretical development of quantum physics focused on isolated systems and did not consider the implications of the interactions with the environment in open systems. These countless interactions are actually the environment becoming entangled with which-path or more appropriately which-state information for a quantum system. Although the amount of which-path information in each individual interaction is tiny, the cumulative effect of all the interactions is decisive. Substantial theoretical and experimental research confirms this conclusion Schlosshauer, ; Zurek, a, b. As noted in the previous section, which-path entanglement results in the loss of quantum superpositions and causes the quantum-to-classical transition. These environmental interactions cause the absence of quantum effects in our everyday world Schlosshauer, ; Zurek, a, b. The elimination of quantum superpositions by environmental interactions is called decoherence. For example, estimates of decoherence times for a dust grain are so fast that superpositions would be extremely difficult to observe Schlosshauer, , p. The decoherence times for larger objects are many orders of magnitude faster. As yet it is not possible to empirically distinguish among different hypotheses. Given that key aspects of quantum physics remain beyond current scientific understanding, it is appropriate to remain cautious in drawing conclusions on this topic. The interconnectedness in the quantum domain that supports entanglement and delayed-choice apparently has a means to incorporate all the relevant factors, conditions, and possibilities in a given situation, even though the factors and conditions may be spread over space and time, and the possibilities may be potential or hypothetical events. Because this interconnectedness does not involve any known energy, the closest analogy appears to be information. As might be expected, the term information is increasingly used in discussions of quantum physics e. However, as yet there has been virtually no consideration of media, symbols, or interpretational infrastructure for the quantum domain. These assumptions attribute to particles the information processing capabilities of life. The analogies he offers to help clarify his ideas about information on the quantum level all involve living systems seeds, people, ships guided by people. However, the theory does not attempt to identify or describe the medium or interpretational infrastructure in the quantum domain that functions as if there was transfer of nonlocal information. Discussions of decoherence often include descriptions that imply that the environment serves as media for symbolic representation of the state of a quantum system. However, there has been no description of an interpretational infrastructure that decodes the symbolic representations and takes corresponding actions for the quantum-to-classical transition.

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Chapter 2 : Quantum Physics, Thermodynamics, and Information

Leading experts from The Physics of Quantum Information network, a European Commission initiative, bring together the most recent results from the emerging area of quantum technology. Written in a consistent style, the book introduces quantum cryptography, quantum teleportation, and quantum.

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.

Chapter 3 : More on Quantum Information | Perimeter Institute

of quantum information theory, that it allows us to make (some) sense of just what information "quantum information" refers to, and that it is useful in understanding and constructing quantum informationprocessingprotocols.

Many, perhaps most, are attempts to eliminate the element of chance or indeterminism that is involved in the so-called collapse of the wave function. The Information Interpretation is simply "standard quantum physics" plus information being recorded irreversibly. Unlike the Copenhagen Interpretation , we offer several visualizations of what is going on in quantum reality, The Information Interpretation is based on three simple premises: When you hear or read that electrons are both waves and particles, think "either-or" - first a wave of possibilities, then an actual particle. Quantum systems evolve in two ways: No knowledge can be gained by a "conscious observer" unless new information has already been irreversibly recorded in the universe. That information can be created and recorded in either the target quantum system or the measuring apparatus. In our two-stage model of free will , an agent first freely generates alternative possibilities , then evaluates them and chooses one, adequately determined by its motives, reasons, desires, etc. First come "free alternatives," then "willed actions. The measuring apparatus is quantal, not deterministic or "classical. The human mind is similarly only statistically determined. There is only one world. It is a quantum world. Ontologically it is indeterministic. Epistemically, common sense and experience incline us to see it as deterministic Information physics claims there is only one world, the quantum world, and the " quantum to classical transition " occurs for any large macroscopic object that contains a large number of atoms. For large enough systems, independent quantum events are "averaged over. The classical laws of motion, with their implicit determinism and strict causality , emerge when objects are large enough so that microscopic events can be ignored, but this determinism is fundamentally statistical and causes are only probabilistic , however near to certainty. With this simple change in terminology, the mysterious process of a wave function "collapsing" becomes more understandable. When a single actuality is realized, the probability for all the non-actualized possibilities goes to zero "collapses" instantaneously. But they could never reconcile the macroscopic irreversibility needed for the second law Information physics is standard quantum physics. The "conscious observer" of the Copenhagen Interpretation is not required for a projection, for the wave-function to "collapse" , for one of the possibilities to become an actuality. What the collapse does require is an interaction between systems that creates information that is irreversible and observable, though not necessarily observed. Among the founders of quantum mechanics, almost everyone agreed that irreversibility is a key requirement for a measurement. Irreversibility introduces thermodynamics into a proper formulation of quantum mechanics, and this is a key element of our information interpretation. But this requirement was never reconciled with classical statistical mechanics, which says that collisions between material particles are reversible. We have shown that it is the interaction of light and matter, both on their own time reversible, that is the origin of irreversibility. Information is not a conserved quantity like energy and mass, despite the view of many mathematical physicists, who generally accept determinism. The universe began in a state of equilibrium with minimal information, and information is being created every day , despite the second law of thermodynamics Classical interactions between large macroscopic bodies do not generate new information. Classical mechanics conserves information. Unlike classical systems however, when there is an interaction between material quantum systems, the two systems become entangled and there may be a change of state in either or both systems. This change of state may create new information. Or if there is an interaction between light and matter the evolution is no longer unitary, there is an irreversible collapse of the wave function. If that information is instantly destroyed, as in most interactions, it may never be observed macroscopically. If, on the other hand, the information is stabilized for some length of time, it may be seen by an observer and considered to be a " measurement. The universe is its own observer! For the information negative entropy to be stabilized, the second law of thermodynamics requires that an amount of positive entropy greater than the negative entropy must be transferred away from the new information structure. Exactly how the universe allows pockets of negative entropy to form as "information structures" we describe as the " cosmic creation process. It continues today as we add information to the sum of human knowledge. Note that despite the Heisenberg principle, quantum mechanical measurements are not always uncertain. What then are the possibilities for new quantum states? Quantum mechanics lets us calculate the probabilities of each of those "possibilities. But for this event to be an "observable" a John Bell "beable" , information must be created and positive entropy must be transferred away from the new information structure, in accordance with our two-stage information creation process. All interpretations of quantum mechanics predict the same experimental results. Information physics is no exception, because the experimental data from quantum experiments is the most accurate in the history of science. Where interpretations differ is in the picture the visualization they provide of what is "really" going on in the microscopic world - the so-called "quantum reality. This is why Bohr and Heisenberg insisted on the path and the " cut " between the quantum event and the mind of an observer. The information interpretation encourages visualization. He and Einstein were right that we should be able to picture quantum reality. But that demands that we accept the reality of quantum possibilities and discontinuous random "quantum jumps," something many modern interpretations do not do. Bohr was of course right that classical physics plays an essential role. His Correspondence Principle allowed him to recover some important physical constants by assuming that the discontinuous quantum jumps for low quantum numbers low "orbits" in his old quantum theory model converged in the limit of large quantum numbers to the continuous radiation emission and absorption of classical electromagnetic theory. We can say that the quantum description of matter also converges to a classical description in the limit of large numbers of quantum particles. We call this "adequate" or statistical determinism. The statistics of averaging over many independent quantum events then produces the " quantum to classical transition " for the same reason as the "law of large numbers" in probability theory. But this is quite wrong, because h is a constant that never goes to zero. In the information interpretation, it is always a quantum world. The conditions needed for ignoring quantum indeterminacy are when the mass of the macroscopic "classical" object is large. Note that the macromolecules of biology are large enough to stabilize their information structures. DNA has been replicating its essential information for billions of years, resisting equilibrium despite the second law of thermodynamics The creation of irreversible new information also marks the transition between the quantum world and the " adequately deterministic " classical world, because the information structure itself must be large enough and stable enough to be seen. Stable new information structures in the dying cat reduce the quantum possibilities and their potential interference effects to a classical actuality. The cat is its own observer. But it always tells us the possibilities - the possible values of any observable, for example. Quantum mechanics is the most accurate physical theory in science, with measurements accurate to thirteen decimal places. In each individual experiment, generally just one of the possibilities becomes an actuality some experiments leave the quantum system in a new superposition of multiple possibilities. In our information interpretation, a possibility is realized or actualized at the moment when information is created about the new state of the system. This new information requires that positive entropy be carried away from the local increase in negative entropy. Note that an "observer" would not be able to make a "measurement" unless there is new information to be "observed. An information approach can help philosophers to think more clearly about quantum physics. Instead of getting trapped in talk about mysterious "collapses of the wave function," "reductions of the wave packet," or the "projection postulate" all important issues , the information interpretation proposes we simply say that one of the "possibilities" has become "actual. And because the other possibilities may have been extremely "distant" from the actuality, their instantanteous disappearances looked to Einstein to violate his principle of relativity, but they do not. Quantum theory lets us put quantitative values on the "probabilities" for each of the "possibilities. This too may be seen as a special kind of information. In the famous " two-slit experiment ," the "possibilities function" travels everywhere, meaning that it passes through both slits, interfering with itself and thus changing the possibilities where the particle might be found. Metaphorically, it "knows" when both slits are open, even if our intuitive classical view imagines that the particle must go through only one. This changes the probabilities associated with each of the possibilities. Possibilities and Information Theory It is of the deepest philosophical significance that information theory is based on the mathematics of probability. If all outcomes were certain , there would be no "surprises" in the universe. Information would be conserved and a universal constant, as some mathematicians mistakenly believe. Information philosophy requires the ontological uncertainty and probabilistic outcomes of modern quantum physics to produce new information. If there is but one possible message, there is no uncertainty, and no information can be communicated. In a universe describable by the classical Newtonian laws of motion, all the information needed to produce the next moment is contained in the positions, motions, and forces on the material particles. Information is constant in a deterministic universe. There is "nothing new under the sun. Without the extraordinary stability of quantized information structures over cosmological time scales, life and the universe we know would not be possible. That stability is the consequence of an underlying digital nature. Quantum mechanics reveals the architecture of the universe to be discrete rather than continuous, to be digital rather than analog. Digital information transfers are essentially perfect. All analog transfers are "lossy. We conclude, contrary to the views of Bohr and Heisenberg, that there is no need for a separate classical world. The classical laws of nature emerge statistically from quantum laws. Quantum laws, which are therefore universally applicable, converge in these two limits of large numbers to classical laws. There is no "transition" from the quantum world to a separate classical world. There is just one world, where quantum physics applies universally, but its mysterious properties, like interference, entanglement, and nonlocality, are normally invisible, averaged over, in the macroscopic world. The problem for an informational interpretation of quantum mechanics is to explain exactly how these two convergences large numbers of particles and large quantum numbers allow continuous and apparently deterministic macroscopic information structures to emerge from the indeterministic and discontinuous microscopic quantum world. We must show how the determinism in the macroscopic world is only a statistical determinism or adequate determinism that results from "averaging over" the large number of independent quantum events happening in a macroscopic object. And even more important, we must show how the occasional magnification or amplification of microscopic quantum events leads to new macroscopic information that makes human beings the "authors of their lives", that makes them "co-creators of our universe," and that guarantees a genuinely open future with alternative possibilities, not in inaccessible "parallel universes" but in the one universe that we have. Feynman proposed to reformulate quantum mechanics based on just three postulates: The probability amplitude is given by adding together the contributions of all paths in configuration space, where paths include not only the most direct from the initial state, but also paths with arbitrary curves that can go arbitrarily far away and then come back to the final state, paths so long that they imply traversal at supraluminal speeds! The overall probability amplitude for a given process is the sum of the contributions over the space of all possible paths of the system in between the initial and final states.

Chapter 4 : The Information Interpretation of Quantum Mechanics

Leading experts from "The Physics of Quantum Information" network, initiated by the European Commission, bring together the most recent results from this emerging area of quantum technology.

To understand information creation, information physics provides new insights into the puzzling " problem of measurement " and the mysterious " collapse of the wave function " in quantum mechanics. Information physics also probes deeply into the second law of thermodynamics to establish the irreversible increase of entropy on a quantum mechanical basis. It is not an attempt to alter the standard quantum mechanics, extending it to theories such as "hidden variables," for example. Information physics simply follows the quantum mechanical and thermodynamic implications of cosmic information structures, especially those that were created before the existence of human observers. Information physics explains the origin of information structures in the universe. Quantum Mechanics In classical mechanics, the material universe is thought to be made up of tiny particles whose motions are completely determined by forces that act between the particles, forces such as gravitation, electrical attractions and repulsions, etc. They provided support for many philosophical ideas about determinism. In classical electrodynamics, electromagnetic radiation light, radio was known to have wave properties such as interference. When the crest of one wave meets the trough of another, the two waves cancel one another. In quantum mechanics, radiation is found to have some particle-like behavior. Energy comes in discrete physically localized packages. But Planck did not think he was describing light particles. It was Einstein who first realized this is what his mathematics was doing. Both curves have a power law increase on one side to a maximum and an exponential decrease on the other side of the maximum. When energy is added to matter, it speeds up all the gas particles, but preserves their number. The molecular velocity curves for different temperatures cross one another because the total number of molecules is the same. With increasing temperature T, however, the number of photons increases at all wavelengths. Planck did not actually believe that radiation came in discrete particles, at least until a dozen years later, and even then he had his doubts. Boltzmann himself had qualms about the reality of chance. Although Einstein also did not like the idea of chancy statistics, he did believe that energy came in packages of discrete "quanta. Nevertheless, it was for the introduction of the quantum of action h that Planck was awarded the Nobel prize in Despite the probability amplitude going through two slits and interfering with itself, experimenters never find parts of electrons. They always are found whole. In John von Neumann explained that two fundamentally different processes are going on in quantum mechanics. A non-causal process, in which the measured electron winds up randomly in one of the possible physical states eigenstates of the measuring apparatus plus electron. According to von Neumann, the particle simply shows up somewhere as a result of a measurement. Information physics says it shows up whenever a new stable information structure is created. Process 1 is thermodynamically irreversible. Process 2 is reversible. This confirms the fundamental connection between quantum mechanics and thermodynamics that is explainable by information physics. Information physics establishes that process 1 may create information. Process 2 is information preserving. At some point, they make the ad hoc assumption that the wave function "collapses. Moreover, without wave functions collapsing, no new information can come into the universe. Nothing unpredicatable would ever emerge. The "Problem" of Measurement Quantum measurement the irreducibly random process of wave function collapse is not a part of the mathematical formalism a perfectly deterministic process of wave function time evolution. It is an ad hoc heuristic description and method of calculation that predicts the probabilities of what will happen when an observer makes a measurement. In many standard discussions of quantum mechanics, and most every popular treatment, it is said that we need the consciousness of a physicist to collapse the wave function. Eugene Wigner and John Wheeler sometimes describe the observer as making up the "mind of the universe. Measurement requires the interaction of something macroscopic, assumed to be large and adequately determined. In physics experiments, this is the observing apparatus. But in general, measurement does not require a conscious observer. It does require information creation or there will be nothing to observe. Thermodynamics The second law of thermodynamics says that the entropy or disorder of a closed physical system increases until it reaches a maximum, the state of thermodynamic equilibrium. It requires that the entropy of the universe is now and has always been increasing. The first law is that energy is conserved. This established fact of increasing entropy has led many scientists and philosophers to assume that the universe we have is running down. They think that means the universe began in a very high state of information, since the second law requires that any organization or order is susceptible to decay. The information that remains today, in their view, has always been here. This fits nicely with the idea of a deterministic universe. There is nothing new under the sun. Physical determinism is "information-preserving. It is in a dynamic state of expansion that is moving away from thermodynamic equilibrium faster than entropic processes can keep up. The maximum possible entropy is increasing much faster than the actual increase in entropy. The difference between the maximum possible entropy and the actual entropy is potential information. Creation of information structures means that in parts of the universe the local entropy is actually going down. Reduction of entropy locally is always accompanied by radiation of entropy away from the local structures to distant parts of the universe, into the night sky for example. Since the total entropy in the universe always increases, the amount of entropy radiated away always exceeds often by many times the local reduction in entropy, which mathematically equals the increase in information. See the Ergodic Hypothesis. But any local decrease in entropy is more than compensated for by increases elsewhere, satisfying the second law. Normal entropy-increasing processes we will call "entropic". Encoding new information requires the equivalent of a quantum measurement - each new bit of information produces a local decrease in entropy but requires that at least one bit generally much much more of entropy be radiated or conducted away. Without violating the inviolable second law of thermodynamics overall, ergodic processes reduce the entropy locally, producing those pockets of cosmos and negative entropy order and information-rich structures that are the principal objects in the universe and in life on earth. Clausius predicted that the universe would end with a "heat death" because of the second law. In Clausius had formulated the second law of thermodynamics. In he showed that for a typical gas like air at standard temperatures and pressures, the gas particles spend most of their time traveling in straight lines between collisions with the wall of a containing vessel or with other gas particles. He defined the "mean free path" of a particle between collisions. Clausius and essentially all physicists since have assumed that gas particles can be treated as structureless "billiard balls" undergoing "elastic" collisions. Elastic means no motion energy is lost to internal friction. He assumed the velocities in the x, y, and z directions were independent. This is a necessary state for the gas to be in equilibrium. Boltzmann then used Newtonian physics to get the same result as Maxwell, which is thus called the Maxwell-Boltzmann distribution. But it ran into immediate objections. The objection is the hypothetical and counterfactual idea of time reversibility. If time were reversed, the entropy would simply decrease. Since the fundamental Newtonian equations of motion are time reversible, this appears to be a paradox. How could the irreversibile increase of the macroscopic entropy result from microscopic physical laws that are time reversible? Boltzmann immediately agreed with Loschmidt that the possibility of decreasing entropy could not be ruled out if the classical motion paths were reversed. Boltzmann then reformulated his H-theorem He analyzed a gas into "microstates" of the individual gas particle positions and velocities. For any "macrostate" consistent with certain macroscopic variables like volume, pressure, and temperature, there could be many microstates corresponding to different locations and speeds for the individual particles. Any individual microstate of the system was intrinsically as probable as any other specific microstate, he said. But the number of microstates consistent with the disorderly or uniform distribution in the equilibrium case of maximum entropy simply overwhelms the number of microstates consistent with an orderly initial distribution. This is the recurrence objection. Given enough time, any system could return to its starting state, which implies that the entropy must at some point decrease. These reversibility and recurrence objections are still prominent in the physics literature. The recurrence idea has a long intellectual history. Ancient Babylonian astronomers thought the known planets would, given enough time, return to any given position and thus begin again what they called a "great cycle," estimated by some at 36, years. Their belief in an astrological determinism suggested that all events in the world would also recur. He had found an analytic solution to the three-body problem and noted that the configuration of three bodies returns arbitrarily close to the initial conditions after calculable times. Even for a handful of planets, the recurrence time is longer than the age of the universe, if the positions are specified precisely enough. Boltzmann accepted the recurrence criticism. He calculated the extremely small probability that entropy would decrease noticeably, even for gas with a very small number of particles He showed the time associated with such an event was years. But the objections in principle to his work continued, especially from those who thought the atomic hypothesis was wrong. Entropy and Quantum Mechanics A quantum mechanical analysis of the microscopic collisions of gas particles these are usually molecules - or atoms in a noble gas can provide revised analyses for the two problems of reversibility and recurrence. Note this requires more than quantum statistical mechanics. It needs the quantum kinetic theory of collisions in gases. There are great differences between Ideal, Classical, and Quantum Gases.

Chapter 5 : Physics at the University Of Virginia - Quantum Information

Quantum resources can be harnessed to solve problems on a quantum computer that cannot realistically be solved on a classical computer. The realization of a large quantum information processor could enable secure communication, quantum computation, and quantum simulation of complex physical systems.

Shuttle Service More on Quantum Information The laws of physics at the atomic scale are very different from our everyday experience of objects the size of a human. At the atomic scale, quantum mechanics rule. Quantum mechanics allow atoms to be in a quantum superposition. Superposition is a little like being in two places at one time. However, if you look at a quantum superposition, the particle has to decide where to be, and you can only ever see it in one of those two places. Quantum information is the effort to both understand and use the properties of the quantum world. The memory of a regular computer consists of a sequence of bits representing some number which in turn might represent a picture or words or anything else. The computer does computations by changing that number according to its program. If we can instead build a computer out of single atoms or other microscopic objects, the memory of the computer could instead be in a quantum superposition. The information stored in such a computer would be quantum information, composed of qubits short for "quantum bit" instead of bits. A quantum computer could perform some computations much faster than any plausible classical computer. Click image to enlarge Binary information 0 or 1 can be stored in the physical state of an electron spin down or spin up The properties of qubits are sometimes very different from the properties of classical bits. Qubits cannot be copied â€" an attempt to do so instead creates an entangled state. Entangled states are special kinds of quantum states that allow two qubits to be more highly correlated than is possible for classical bits. These special properties allow other surprising applications of quantum mechanics. For instance, quantum cryptography allows more secure secret codes by taking advantage of the resistance of qubits to copying. One major focus of quantum information researchers at Perimeter is to understand the properties of quantum information. Sometimes this takes the form of figuring out what new technologies quantum information can enable such as new quantum cryptography protocols. Sometimes, we instead find limits on the power of quantum information for instance, by discovering that certain computational problems are likely to be too hard for even a quantum computer to solve. Sometimes we try to pinpoint the ways in which quantum systems are different from classical systems by studying the distinction between quantum systems that can be easily simulated on a classical computer and those that cannot. And sometimes, we simply try to understand the strange behavior of quantum states with no particular application in mind for instance, by studying the structure of complicated entangled states. Actually building a quantum computer is a daunting task because of the challenges involved in manipulating individual atoms with high precision. Some of our associate faculty at the Institute for Quantum Computing IQC are engaged in experiments aimed at constructing quantum computers. At Perimeter, we do a good deal of theoretical work that can help in this long-term task. We study quantum error correction and fault-tolerant quantum computation to allow experimenters to more easily construct large quantum computers, without requiring that the individual components of the quantum computer be perfect. We also think about improved ways to measure the properties of quantum systems, particularly those which are to be used to build a quantum computer. The deeper insight we are trying to develop into the properties of quantum states pays off in other areas of physics as well, since so many systems of interest to physicists are inherently quantum-mechanical. A number of Perimeter researchers have a shared interest in quantum information and condensed matter or quantum foundations, and we have also pursued applications of quantum information ideas to particle physics, astronomy, string theory, and quantum gravity. What does it mean and how can we use it? The Physics of Information: Compared with our everyday experience, the quantum world â€" the world of the very small, of atoms and elementary particles â€" is incredibly bizarre.

Chapter 6 : Quantum Information

DOWNLOAD PDF THE PHYSICS OF QUANTUM INFORMATION

The superposition principle plays the most central role in all considerations of quantum information, and in most of the "gedanken" experiments and even the paradoxes of quantum mechanics.

Chapter 7 : APS Physics | Division of Quantum Information

The leading experts from "The Physics of Quantum Information" network, an initiative of the European Commission, bring together the most recent results of the emerging area of quantum technology.

Chapter 8 : Physical information - Wikipedia

Written in a consistent style, the book introduces quantum cryptography, quantum teleportation, and quantum computation, considering both theory and the latest experiments. Thus scientists working in the field and advanced students will find it to be a rich source of information on this exciting new area.

Chapter 9 : Nature and Meaning of Information in Physics

Quantum information science began about 30 years ago as the union of two of the biggest scientific developments of the last century, quantum mechanics and computer science. The original motivation was to understand the new possibilities offered by quantum mechanics to information processing and computation.