Chapter 1 : The Role of Decoherence in Quantum Mechanics (Stanford Encyclopedia of Philosophy)

Quantum decoherence is the loss of quantum coherence. In quantum mechanics, particles such as electrons are described by a wave function, a mathematical description of the quantum state of a system; the probabilistic nature of the wave function gives rise to various quantum effects.

Essentials of Decoherence The two-slit experiment is a paradigm example of an interference experiment. One repeatedly sends electrons or other particles through a screen with two narrow slits, the electrons impinge upon a second screen, and we ask for the probability distribution of detections over the surface of the screen. In order to calculate this, one cannot just take the probabilities of passage through the slits, multiply with the probabilities of detection at the screen conditional on passage through either slit, and sum over the contributions of the two slits. There are, however, situations in which this interference term for detections at the screen is not observed, i. The disappearence of the interference term, however, can happen also spontaneously, when no collapse true or otherwise is presumed to happen. Namely, if some other systems say, sufficiently many stray cosmic particles scattering off the electron suitably interact with the wave between the slits and the screen. In this case, the reason why the interference term is not observed is because the electron has become entangled with the stray particles. Probabilities for results of measurements performed only on the electron are calculated as if the wave function had collapsed to one or the other of its two components, but in fact the phase relations have merely been distributed over a larger system. Several features of interest arise in models of such interactions although by no means are all such features common to all models. One feature of these environmental interactions is that they suppress interference between states from some preferred set, be it a discrete set of states e. Formally, this is reflected in the at least approximate diagonalisation of the reduced state of the system of interest in the basis of privileged states whether discrete or continuous. These preferred states can be characterised in terms of their robustness or stability with respect to the interaction with the environment. Roughly speaking, the system gets entangled with the environment, but the states between which interference is suppressed are the ones that would themselves get least entangled with the environment under further interaction. This information can later be acquired by an observer without further disturbing the system we observeâ€"however that may be interpretedâ€"whether the cat is alive or dead by intercepting on our retina a small fraction of the light that has interacted with the cat. The concept of a strict superselection rule means that there are some observablesâ€"called classical in technical terminologyâ€"that commute with all observables for a review, see Wightman Intuitively, these observables are infinitely robust, since no possible interaction can disturb them at least as long as the interaction Hamiltonian is considered to be an observable. By an effective superselection rule one means, analogously, that certain observables e. In the case of the chiral molecule, the left- and right-handed states are indeed characterised by different spatial configurations of the atoms in the molecule. Rough intuitions should suffice here; see also the entries on quantum mechanics and the section on the measurement problem in the entry on philosophical issues in quantum theory. The resulting localisation can be on a very short length scale, i. Even more strikingly, the time scales for this process are minute. This coherence length is reached after a microsecond of exposure to air, and suppression of interference on a length scale of cm is achieved already after a nanosecond. One should be wary of overgeneralisations, as already pointed out, but this is certainly a feature of many concrete examples that have been investigated. What about classical dynamical behaviour? Interference is a dynamical process that is distinctively quantum, so, intuitively, lack of interference might be thought of as classical-like. To make the intuition more precise, think of the two components of the wave going through the slits. If there is an interference term in the probability for detection at the screen, it must be the case that both components are indeed contributing to the particle manifesting itself on the screen. But if the interference term is suppressed, one can at least formally imagine that each detection at the screen is a manifestation of only one of the two components of the wave function, either the one that went through the upper slit, or the one that went through the lower slit. Thus, there is a sense in which one can recover at least one dynamical aspect of a classical description, a trajectory of sorts: In the case of continuous models of decoherence based on the analogy of approximate joint measurements of position and momentum, one can do even better. In this case, the trajectories at the level of the components the trajectories of the preferred states will approximate surprisingly well the corresponding classical Newtonian trajectories. As a matter of fact, one should expect slight deviations from Newtonian behaviour. These are due both to the tendency of the individual components to spread and to the detection-like nature of the interaction with the environment, which further enhances the collective spreading of the components a narrowing in position corresponds to a widening in momentum. These deviations appear as noise, i. Other examples include trajectories of a harmonic oscillator in equilibrium with a thermal bath, and trajectories of particles in a gas without which the classical derivation of thermodynamics from statistical mechanics would make no sense; see below Section 4. None of these features are claimed to obtain in all cases of interaction with some environment. It is a matter of detailed physical investigation to assess which systems exhibit which features, and how general the lessons are that we might learn from studying specific models. In particular, one should beware of common overgeneralisations. On the other hand, there are also very good examples of decoherence-like interactions affecting microscopic systems, such as in the interaction of alpha particles with the gas in a bubble chamber. And further, there are arguably macroscopic systems for which interference effects are not suppressed. For instance, it has been shown to be possible to sufficiently shield SQUIDS a type of superconducting devices from decoherence for the purpose of observing superpositions of different macroscopic currentsâ€"contrary to what one had expected see e. Leggett , and esp. Anglin, Paz and Zurek examine some less well-behaved models of decoherence and provide a useful corrective as to the limits of decoherence. In particular, we can assign probabilities to the alternative trajectories, so that probabilities for detection at the screen can be calculated by summing over intermediate events. In a nutshell, the formalism is as follows. Such histories form a so-called alternative and exhaustive set of histories. We wish to define probabilities for the set of histories. But we can impose, as a consistency or weak decoherence condition, precisely that interference terms should vanish for any pair of distinct histories. If this is satisfied, we can view 2 as defining the distribution functions for a stochastic process with the histories as trajectories. There are some differences between the various authors, but we shall gloss them over. Decoherence in the sense of this abstract formalism is thus defined simply by the condition that quantum probabilities for wave components at a later time may be calculated from quantum probabilities for wave components at an earlier time and quantum conditional probabilities according to the standard classical formula, i. Models of dynamical decoherence fall under the scope of decoherence thus defined, but the abstract definition is much more general. As such, it is particularly useful as a tool for describing decoherence in connection with attempts to solve the problem of the classical regime in the context of various different interpretational approaches to quantum mechanics. The fact that interference is typically very well suppressed between localised states of macroscopic objects suggests that it is relevant to why macroscopic objects in fact appear to us to be in localised states. A stronger claim is that decoherence is not only relevant to this question but by itself already provides the complete answer. In the special case of measuring apparatuses, it would explain why we never observe an apparatus pointing, say, to two different results, i. As pointed out by many authors, however e. Adler ; Zeh , pp. The measurement problem, in a nutshell, runs as follows. Quantum mechanical systems are described by wave-like mathematical objects vectors of which sums superpositions can be formed see the entry on quantum mechanics. The problem is that, while we may accept the idea of microscopic systems being described by such sums, the meaning of such a sum for the composite of electron and apparatus is not immediately obvious. Now, what happens if we include decoherence in the description? Decoherence tells us, among other things, that plenty of interactions are taking place all the time in which differently localised states of macroscopic systems couple to different states of their environment. In particular, the differently localised states of the macroscopic system could be the states of the pointer of the apparatus registering the different x-spin values of the electron. Again, the meaning of such a sum for the composite system is not obvious. We are left with the following choice whether or not we include decoherence: Thus, decoherence as such does not provide a solution to the measurement problem, at least not unless it is combined with an appropriate interpretation of the theory whether this be one that attempts to solve the measurement problem, such as Bohm, Everett or GRW; or one that attempts to dissolve it, such as various versions of the Copenhagen interpretation. Some of the main workers in the field such as Zeh and perhaps Zurek suggest that decoherence is most naturally understood in terms of Everett-like interpretations see below Section 3. Pearle and philosophers e. As such it has much to offer to the philosophy of quantum mechanics. At first, however, it seems that discussion of environmental interactions should actually exacerbate the existing problems. Intuitively, if the environment is carrying out, without our intervention, lots of approximate position measurements, then the measurement problem ought to apply more widely, also to these spontaneously occurring measurements. Although the different components that couple to the environment will be individually incredibly localised, collectively they can have a spread that is many orders of magnitude larger. That is, the state of the object and the environment could be a superposition of zillions of very well localised terms, each with slightly different positions, and that are collectively spread over a macroscopic distance, even in the case of everyday objects. To put it crudely: And indeed, discussing the measurement problem without taking decoherence fully into account may not be enough, as we shall illustrate by the case of some versions of the modal interpretation in Section 3. The question is then whether, if viewed in the context of any of the main foundational approaches to quantum mechanics, these classical aspects can be taken to explain corresponding classical aspects of the phenomena. The answer, perhaps unsurprisingly, turns out to depend on the chosen approach, and in the next section we shall discuss in turn the relation between decoherence and several of the main approaches to the foundations of quantum mechanics. Even more generally, one can ask whether the results of decoherence could thus be used to explain the emergence of the entire classicality of the everyday world, i. As we have mentioned already, there are cases in which a classical description is not a good description of a phenomenon, even if the phenomenon involves macroscopic systems. There are also cases, notably quantum measurements, in which the classical aspects of the everyday world are only kinematical definiteness of pointer readings , while the dynamics is highly non-classical indeterministic response of the apparatus. In this generality the question is clearly too hard to answer, depending as it does on how far the physical programme of decoherence Zeh , p. We shall thus postpone the partly speculative discussion of how far this programme might go until Section 4. Decoherence and Approaches to Quantum Mechanics There is a wide range of approaches to the foundations of quantum mechanics. A convenient way of classifying these approaches is in terms of their strategies for dealing with the measurement problem. Such approaches may have intuitively little to do with decoherence since they seek to suppress precisely those superpositions that are created by decoherence. Nevertheless their relation to decoherence is interesting. Among collapse approaches Section 3. Of these, the most developed are the so-called pilot-wave theories Section 3. Finally, there are approaches that seek to solve or dissolve the measurement problem strictly by providing an appropriate interpretation of the theory. We shall be analysing these approaches specifically in their relation to decoherence we discuss the Everett interpretation in Section 3. There is some ambiguity in how to interpret von Neumann. He may have been advocating some sort of special access to our own consciousness that makes it appear to us that the wave function has collapsed; this would suggest a phenomenological reading of Process I. Alternatively, he may have proposed that consciousness plays some causal role in precipitating the collapse; this would suggest that Process I is a physical process taking place in the world on a par with Process II. This is often referred to as the movability of the von Neumann cut between the subject and the object, or some similar phrase. Collapse could occur anywhere along the so-called von Neumann chain: Von Neumann thus needs to show that all of these models are equivalent, as far as the final predictions are concerned, so that he can indeed maintain that collapse is related to consciousness, while in practice applying the projection postulate at a much earlier and more practical stage in the description. Von Neumann poses this problem in Section VI. Then in Section VI.

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Chapter 2 : Decoherence and the theory of continuous quantum measurements - IOPscience

Decoherence is the term used to describe the destruction of phase relations in the state of a quantum mechanical system, as a result of a dynamical process. According to the Superposition Principle, any two state vectors in a Hilbert.

I understand that this is still very much an active area of research but it seems to me that there is a general belief that decoherence is some sort of holy grail? More recently however, I have gained the impression that a lot of people regard decoherence as the solution to this problem, but I have also seen specific claims that decoeherence does not attempt to resolve the measurement problem at all. Is the measurement problem still a thing? So then, why are so many physicists behaving as though the problem has been solved? A short outline of the paper: Why Decoherence has not Solved the Measurement Problem: A Response to P. My main test, allowing me to bypass the extensive discussion, was a quick, unsuccessful search in the index for the word decoherence which describes the process that used to be called collapse of the wave function. The concept is now experimentally veried by beautiful atomic beam techniques quantifying the whole process. In a somewhat similar vein, Tegmark and Wheeler state in a recent Scientic American article discussing the many-worlds" interpretation of quantum mechanics and decoherence, It is my understanding that decoherence is a gradual process? Something that occurs quite rapidly but not instantaneously correct? So then, what does this have to say about the old notion of the discontinuous "qauntum leap"? Does the mainstream physics community still regard this "collapse" process as a discontinuous thing or is my understanding out of date? This may not be worded correctly but here goes When does decoherence occur? Take for example the double-slit experiment, if "collapse" occurs before the two waves interfere, then there will be no interference pattern. If "collapse" occurs after interference then there will be an interference pattern. This tell me that the process of "collapse" has a definite time of occurrence. So then, why does it happen when it does? What is so different about a "measurement apparatus" compared to a molecule of nitrogen in the air or some other such thing? Precisely how many free particles does an object need to have before we call it a "classical" object?!

Chapter 3 : [quant-ph/] Decoherence, the measurement problem, and interpretations of quantum mechanic

The phenomenon of quantum decoherence does not provide a final answer to the measurement problem but in a practical sense lets us push the difficulties farther away. At issue is the Born probability rule and the associated wavefunction collapse.

As an analogue, in quantum mechanics a system is described by its quantum state , which contains the probabilities of possible positions and momenta. In mathematical language, all possible pure states of a system form an abstract vector space called Hilbert space , which is typically infinite-dimensional. A pure state is represented by a state vector in the Hilbert space. Once a quantum system has been prepared in laboratory, some measurable quantity such as position or energy is measured. For pedagogic reasons, the measurement is usually assumed to be ideally accurate. The state of a system after measurement is assumed to " collapse " into an eigenstate of the operator corresponding to the measurement. Repeating the same measurement without any evolution of the quantum state will lead to the same result. If the preparation is repeated, subsequent measurements will likely lead to different results. The predicted values of the measurement are described by a probability distribution , or an "average" or "expectation" of the measurement operator based on the quantum state of the prepared system. The measurement process is often considered as random and indeterministic. In some interpretations of quantum mechanics , the result merely appears random and indeterministic, whereas in other interpretations the indeterminism is core and irreducible. A significant element in this disagreement is the issue of " collapse of the wave function " associated with the change in state following measurement. There are many philosophical issues and stances and some mathematical variations takenâ€”and near universal agreement that we do not yet fully understand quantum reality. In any case, our descriptions of dynamics involve probabilities, not certainties. Quantitative details[edit] The mathematical relationship between the quantum state and the probability distribution is, again, widely accepted among physicists, and has been experimentally confirmed countless times. This section summarizes this relationship, which is stated in terms of the mathematical formulation of quantum mechanics. Measurable quantities "observables" as operators[edit] Main article: Observable It is a postulate of quantum mechanics that all measurements have an associated operator called an observable operator, or just an observable , with the following properties: The observable is a self-adjoint or Hermitian operator mapping a Hilbert space namely, the state space , which consists of all possible quantum states into itself. Any quantum state can be represented as a superposition of the eigenstates of an observable. The possible outcomes of a measurement are precisely the eigenvalues of the given observable. For each eigenvalue there are one or more corresponding eigenvectors eigenstates. A measurement results in the system being in the eigenstate corresponding to the eigenvalue result of the measurement. If the eigenvalue determined from the measurement corresponds to more than one eigenstate "degeneracy" , instead of being in a definite state, the system is in a sub-space of the measurement operator corresponding to all the states having that eigenvalue. Important examples of observables are:

Chapter 4 : Measurement problem - Wikipedia

The measurement problem in quantum mechanics is the problem of how (or whether) wave function collapse occurs. The inability to observe this process directly has given rise to different interpretations of quantum mechanics and poses a key set of questions that each interpretation must answer.

A mechanism is arranged to kill a cat if a quantum event, such as the decay of a radioactive atom, occurs. Thus the fate of a large-scale object, the cat, is entangled with the fate of a quantum object, the atom. Each of these possibilities is associated with a specific nonzero probability amplitude ; the cat seems to be in some kind of "combination" state called a " quantum superposition ". However, a single, particular observation of the cat does not measure the probabilities: After the measurement the cat is definitively alive or dead. How are the probabilities converted into an actual, sharply well-defined outcome? Interpretations of quantum mechanics The Copenhagen interpretation is the oldest and probably still the most widely held interpretation of quantum mechanics. According to the von Neumannâ€"Wigner interpretation , the causative agent in this collapse is consciousness. Instead, the act of measurement is simply an interaction between quantum entities, e. Everett also attempted to demonstrate the way that in measurements the probabilistic nature of quantum mechanics would appear; work later extended by Bryce DeWitt. De Broglieâ€"Bohm theory tries to solve the measurement problem very differently: The role of the wave function is to generate the velocity field for the particles. These velocities are such that the probability distribution for the particle remains consistent with the predictions of the orthodox quantum mechanics. According to de Broglieâ€"Bohm theory, interaction with the environment during a measurement procedure separates the wave packets in configuration space, which is where apparent wave function collapse comes from, even though there is no actual collapse. The Ghirardiâ€"Riminiâ€"Weber GRW theory differs from other collapse theories by proposing that wave function collapse happens spontaneously. Particles have a non-zero probability of undergoing a "hit", or spontaneous collapse of the wave function, on the order of once every hundred million years. Since the entire measurement system is entangled by quantum entanglement , the collapse of a single particle initiates the collapse of the entire measurement apparatus. Erich Joos and Heinz-Dieter Zeh claim that the phenomenon of quantum decoherence , which was put on firm ground in the s, resolves the problem. Zeh further claims that decoherence makes it possible to identify the fuzzy boundary between the quantum microworld and the world where the classical intuition is applicable. See, for example, Zurek, [3] Zeh [10] and Schlosshauer. It is fair to say that no decisive conclusion appears to have been reached as to the success of these derivations. As it is well known, [many papers by Bohr insist upon] the fundamental role of classical concepts. The experimental evidence for superpositions of macroscopically distinct states on increasingly large length scales counters such a dictum. Superpositions appear to be novel and individually existing states, often without any classical counterparts. Only the physical interactions between systems then determine a particular decomposition into classical states from the view of each particular system. Thus classical concepts are to be understood as locally emergent in a relative-state sense and should no longer claim a fundamental role in the physical theory. A fourth approach is given by objective-collapse models. These nonlinear modifications are of stochastic nature and lead to a behaviour that for microscopic quantum objects, e. For macroscopic objects, however, the nonlinear modification becomes important and induces the collapse of the wave function. Objective-collapse models are effective theories. The stochastic modification is thought of to stem from some external non-quantum field, but the nature of this field is unknown. The main difference of objective-collapse models compared to the other approaches is that they make falsifiable predictions that differ from standard quantum mechanics. Experiments are already getting close to the parameter regime where these predictions can be tested. The hypothesis at the basis of this approach is that in a typical quantum measurement there is a condition of lack of knowledge about which interaction between the measured entity and the measuring apparatus is actualized at each run of the experiment. One can then show that the Born rule can be derived by considering a uniform average over all these possible measurement-interactions.

Chapter 5 : Quantum Measurements and Decoherence : Models and Phenomenology (eBook,) [blog.quint

Abstract: Environment-induced decoherence and superselection have been a subject of intensive research over the past two decades, yet their implications for the foundational problems of quantum mechanics, most notably the quantum measurement problem, have remained a matter of great controversy.

Decoherence theorists attribute the absence of macroscopic quantum effects like interference which is a coherent process to interactions between a quantum system and the larger macroscopic environment. They maintain that no system can be completely isolated from the environment. The decoherence which accounts for the disappearance of macroscopic quantum effects is shown experimentally to be correlated with the loss of isolation. Niels Bohr maintained that a macroscopic apparatus used to "measure" quantum systems must be treated classically. John von Neumann , on the other hand, assumed that everything is made of quantum particles, even the mind of the observer. This led him and Werner Heisenberg to say that a "cut" must be located somewhere between the quantum system and the mind, which would operate in a sort of "psycho-physical parallelism. These only show up in large numbers of repeated identical experiments that make measurements on single particles at a time. Interference is never directly "observed" in a single experiment. When interference is present in a system, the system is called "coherent. Interference experiments require that the system of interest is extremely well isolated from the environment, except for the "measurement apparatus. It can be a photographic plate or an electron counter, anything capable of registering a quantum level event, usually by releasing a cascade of metastable processes that amplify the quantum-level event to the macroscopic "classical" world, where an "observer" can see the result. Quantum processes are happening all the time. Most quantum events are never observed, though they can be inferred from macroscopic phenomenological observations. To be sure, those quantum events that are "measured" in a physics experiment which is set up to measure a certain quantity are dependent on the experimenter and the design of the experiment. To measure the electron spin in a Stern-Gerlach experiment , for example, the experimenter is " free to choose " to measure, for example, the z-component of the spin, rather than the x- or y-component. This will influence quantum level events in the following ways: We are "free to choose" the experiment to perform. If we measure position for example, the precise position value did not exist in some sense immediately before the measurement. On the other hand, we could not create the particular value for the position. This is a random choice made by Nature, as P. The "decoherence program" of H. They call this the " quantum to classical transition. This is the method used to calculate the probabilities of various outcomes, which probabilities are confirmed to several significant figures by the statistics of large numbers of identically prepared experiments. Some also accept the axiom of measurement, although some of them question the link between eigenstates and eigenvalues. The decoherence program hopes to offer insights into several other important phenomena: What Zurek calls the "einselection" environment-induced superselection of preferred states the so-called "pointer states" in a measurement apparatus. The role of the observer in quantum measurements. Nonlocality and quantum entanglement which is used to "derive" decoherence. The origin of irreversibility by "continuous monitoring". The approach to thermal equilibrium. The decoherence program finds unacceptable these aspects of the standard quantum theory: Quantum "jumps" between energy eigenstates. In particular, explanation of the collapse as a "mere" increase of information. The "appearance" of "particles. Decoherence theorists admit that some problems remain to be addressed: The "problem of outcomes. As Tegmark and Wheeler put it: The main motivation for introducing the notion of wave-function collapse had been to explain why experiments produced specific outcomes and not strange superpositions of outcomes Scientific American, February , p. Decoherence advocates therefore look to other attempts to formulate quantum mechanics. Also called " interpretations ," these are more often reformulations , with different basic assumptions about the foundations of quantum mechanics. The DeBroglie-Bohm "pilot-wave" or "hidden variables" formulation. The Everett-DeWitt "relative-state" or "many worlds" formulation. The Ghirardi -Rimini-Weber "spontaneous collapse" formulation. Note that these "interpretations" are often in serious conflict with one another. Dieter Zeh , the founder of decoherence, sees one of two possibilities: So it appears worth mentioning at this point that environmental decoherence, derived by tracing out unobserved variables from a universal wave function, readily describes precisely the apparently observed "quantum jumps" or "collapse events. However, I-Phi does it while accepting the standard assumptions of orthodox quantum physics. We briefly review the standard theory of quantum mechanics and compare it to the "decoherence program," with a focus on the details of the measurement process. We divide measurement into several distinct steps, in order to clarify the supposed "measurement problem" mostly the lack of macroscopic state superpositions and perhaps "solve" it. The most famous example of probability-amplitude-wave interference is the two-slit experiment. Interference is between the probability amplitudes whose absolute value squared gives us the probability of finding the particle at various locations behind the screen with the two slits in it. Finding the particle at a specific location is said to be a "measurement. If the system was "prepared" in one of these "eigenstates," then the measurement will find it in that state with probability one that is, with certainty. It is said to be in "superposition" of those basic states. Between measurements, the time evolution of a quantum system in such a superposition of states is described by a unitary transformation U t, t0 that preserves the same superposition of states as long as the system does not interact with another system, such as a measuring apparatus. As long as the quantum system is completely isolated from any external influences, it evolves continuously and deterministically in an exactly predictable causal manner. Whenever the quantum system does interact however, with another particle or an external field, its behavior ceases to be causal and it evolves discontinuously and indeterministically. This acausal behavior is uniquely quantum mechanical. Nothing like it is possible in classical mechanics. Most attempts to "reinterpret" or "reformulate" quantum mechanics are attempts to eliminate this discontinuous acausal behavior and replace it with a deterministic process. We must clarify what we mean by "the quantum system" and "it evolves" in the previous two paragraphs. This brings us to the mysterious notion of "wave-particle duality. But the wave is an abstract quantity whose absolute square is the probability of finding a quantum particle somewhere. It is distinctly not the particle, whose exact position is unknowable while the quantum system is evolving deterministically. It is the probability amplitude wave that interferes with itself. Particles, as such, never interfere although they may collide. Note that we never "see" the superposition of particles in distinct states. When the particle interacts, with the measurement apparatus for example, we always find the whole particle. For example, an electron "jumps" from one orbit to another, absorbing or emitting a discrete amount of energy a photon. When a photon or electron is fired at the two slits, its appearance at the photographic plate is sudden and discontinuous. The probability wave instantaneously becomes concentrated at the location of the particle. There is now unit probability certainty that the particle is located where we find it to be. This is described as the "collapse" of the wave function. Einstein said that some mysterious "spooky action-at-a-distance" must act to prevent the appearance of a second particle at a distant point where a finite probability of appearing had existed just an instant earlier. Animation of a wave function collapsing - click to restart Whereas the abstract probability amplitude moves continuously and deterministically throughout space, the concrete particle moves discontinuously and indeterministically to a particular point in space. For this collapse to be a "measurement," the new information about which location or state the system has collapsed into must be recorded somewhere in order for it to be "observable" by a scientist. But the vast majority of quantum events - e. Zeh describes how quantum systems may be "measured" without the recording of information. It is therefore a plausible experimental result that the interference disappears also when the passage [of an electron through a slit] is "measured" without registration of a definite result. The latter may be assumed to have become a "classical fact" as soon as the measurement has irreversibly "occurred". A quantum phenomenon may thus "become a phenomenon" without being observed. Bohr later spoke of objective irreversible events occurring in the counter. However, what precisely is an irreversible quantum event? According to Bohr this event can not be dynamically analyzed. Analysis within the quantum mechanical formalism demonstrates nonetheless that the essential condition for this "decoherence" is that complete information about the passage is carried away in some objective physical form. This means that the state of the environment is now quantum correlated entangled with the relevant property of the system such as a passage through a specific slit. This need not happen in a controllable way as in a measurement: In contrast to statistical correlations, quantum correlations characterize real though nonlocal quantum states - not any lack of information. In particular, they may describe individual physical properties, such as the non-additive total angular momentum J2 of a composite system at any distance. A particle collides with another microscopic particle or with a macroscopic object which might be a measuring apparatus. If the collision is with a large enough macroscopic apparatus, it might be capable of recording the new system state information, by changing the quantum state of the apparatus into a "pointer state" correlated with the new system state. But this new information will not be indelibly recorded unless the recording apparatus can transfer entropy away from the apparatus greater than the negative entropy equivalent of the new information to satisfy the second law of thermodynamics. This is the second requirement in every two-step creation of new information in the universe. The new information could be useful it is negative entropy to an information processing system, for example, a biological cell like a brain neuron. The new information could be meaningful to an information processing agent who could not only observe it but understand it. Now neurons would fire in the mind of the conscious observer that John von Neumann and Eugene Wigner thought was necessary for the measurement process to occur at all. Von Neumann perhaps influenced by the mystical thoughts of Neils Bohr about mind and body as examples of his "complementarity. The Measurement Problem So what exactly is the "measurement problem?

Chapter 6 : Quantum decoherence - Wikipedia

The decoherence of a quantum system, i.e., its becoming partly classical, results from its interaction with the environment and is well described in terms of continuous quantum measurement theory.

This has analogies with the classical phase space. A classical phase space contains a real-valued function in 6N dimensions each particle contributes 3 spatial coordinates and 3 momenta. Our "quantum" phase space, on the other hand, involves a complex-valued function on a 3N-dimensional space. Aside from these differences, however, the rough analogy holds. Different previously isolated, non-interacting systems occupy different phase spaces. Alternatively we can say that they occupy different lower-dimensional subspaces in the phase space of the joint system. For a macroscopic system this will be a very large dimensionality. When two systems and the environment would be a system start to interact, though, their associated state vectors are no longer constrained to the subspaces. Instead the combined state vector time-evolves a path through the "larger volume", whose dimensionality is the sum of the dimensions of the two subspaces. The extent to which two vectors interfere with each other is a measure of how "close" they are to each other formally, their overlap or Hilbert space multiplies together in the phase space. When a system couples to an external environment, the dimensionality of, and hence "volume" available to, the joint state vector increases enormously. Each environmental degree of freedom contributes an extra dimension. Each expansion corresponds to a projection of the wave vector onto a basis. The basis can be chosen at will. Let us choose an expansion where the resulting basis elements interact with the environment in an element-specific way. Such elements willâ€”with overwhelming probabilityâ€”be rapidly separated from each other by their natural unitary time evolution along their own independent paths. After a very short interaction, there is almost no chance of any further interference. The process is effectively irreversible. The different elements effectively become "lost" from each other in the expanded phase space created by coupling with the environment; in phase space, this decoupling is monitored through the Wigner quasi-probability distribution. The original elements are said to have decohered. The environment has effectively selected out those expansions or decompositions of the original state vector that decohere or lose phase coherence with each other. This is called "environmentally-induced superselection", or einselection. Any elements that decohere from each other via environmental interactions are said to be quantum-entangled with the environment. The converse is not true: Any measuring device or apparatus acts as an environment, since at some stage along the measuring chain, it has to be large enough to be read by humans. It must possess a very large number of hidden degrees of freedom. In effect, the interactions may be considered to be quantum measurements. As a result of an interaction, the wave functions of the system and the measuring device become entangled with each other. If the measuring device has many degrees of freedom, it is very unlikely for this to happen. As a consequence, the system behaves as a classical statistical ensemble of the different elements rather than as a single coherent quantum superposition of them. Using Dirac notation , let the system initially be in the state.

Chapter 7 : Quantum decoherence and measurement | Physics Forums

Quantum measurement and decoherence G. W. Ford, J. T. Lewis, and R. F. O'Connellâ€ School of Theoretical Physics, Dublin Institute for Advanced Studies, 10 Burlington Road, Dublin 4, Ireland.*

The trouble had to do with reconciling the quantum world with the macroscopic classical world. Logic itself was different. He came up with a simple equation, essentially: It involves no physical assumptions, just pure mathematics. Realism means that the things around us exist independently of whether we observe them. If there are mathematical sets A, B, and C those sets exist independent of the mathematician. In the quantum world, if we observe set A, it can change set B and C. The order that we observe the sets matters too. Realism means the proverbial tree that falls in the forest makes a sound whether we hear it or not. The tree exists in a superposition of states both making and not making a sound until someone, or something, observes it. This does not sound like a very plausible description of our practical experience though. Realism does seem to be a property of the macroscopic universe. The most common interpretation of quantum mechanics was called the Copenhagen interpretation. It was a successful theory in that it worked â€" we could accurately predict what the results of a measurement would be. Still, this was kind of a band-aid on an otherwise elegant theory and the idea of having two entirely different logical views of the world was unsettling. Some physicists dissented and argued that it was not the responsibility of physicists to interpret the world, it was enough to have the equations to make predictions. This paradox became known as the quantum measurement problem and was one of the great unsolved mysteries of physics for over one hundred years. In fact, many brilliant physicists gave up on the idea of one Universe â€" to them it would take an infinite spectrum of constantly branching parallel Universes to understand quantum mechanics. We now understand entanglement is the first step in the measurement process, followed by asymptotic convergence to pointer states of the apparatus. In this paper the authors showed that the measurement problem can be understood within the context of quantum statistical mechanics alone â€" pure quantum mechanics and statistics. No outside assumptions, no wave function collapse. All smooth, time reversible , unitary evolution of the wave function. Then, two extreme cases are examined: This gives the appearance of wave-function collapse, but it is not that, it is a smooth convergence, maybe like a lens focusing light to a single point. This is the case when the number of atoms, which all have magnetic moments , in the measuring device is large. At first this seems a counter-intuitive result. One might expect the entanglement to keep spreading throughout and into the environment in an increasingly chaotic and complex way, but this does not happen. The mathematics prove it. In the second extreme, when the coupling to the environment is much stronger , the system experiences decoherence â€" the case when the number of atoms in the measuring device is small. This happens before entanglement can cascade to a pointer state and so the system fails to register a measurement. In other words, it may be that measurements in general, like the cloud chamber photos of particle physics or the images of molecular spectroscopy, are just asymptotic pointer states â€" no more wave-particle duality , just wave functions. Just more or less localized wave functions. It means that the whole of the classical world may just be an asymptotic state of the much more complex quantum world. Measurement happens often because pointer states are abundant, so the convergence gives the illusion of realism. And, in the vast majority of cases, this approximation works great. It may turn out that biological systems occupy a middle ground between these two extremes â€" many weak couplings but not so many strong ones. Lots of densely packed quantum states, but a distinct absence of pointers. In such a system, superpositions could potentially be preserved for longer time scales because it may be that the rate of growth of entanglement propagating through the system may equal the rate of decoherence. It may even be that no individual particle remains entangled but a dynamic wave of entanglement â€" an entanglement envelope â€" followed by a wave of decoherence will describe the quantum dynamics. A dynamic situation where entanglement is permanent, but always on the move.

Chapter 8 : VI. Solving the Quantum Measurement Problem â€" Pointers, Decoherence & Quantum Dynan

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Decoherence is the study of interactions between a quantum system (generally a very small number of microscopic particles like electrons, photons, atoms, molecules, etc. - often just a single particle) and the larger macroscopic environment, which is normally treated "classically," that is, by ignoring quantum effects, but which decoherence theorists study quantum mechanically.

Chapter 9 : What is Decoherence?

Solving the Quantum Measurement Problem - Pointers, Decoherence & Quantum Dynamics Posted on January 11, January 20, by I, Quantum Despite all the incredible practical success with quantum technology there was still an incompleteness about quantum's interpretation.