DOWNLOAD PDF INTERPRETING QUANTUM MECHANICS

Chapter 1 : Interpretation Quantum Mechanics by Roland OmnÃ¨s

An interpretation of quantum mechanics is an attempt to explain how the mathematical theory of quantum mechanics corresponds to calendrierdelascience.comgh quantum mechanics has held up to rigorous and extremely precise tests in an extraordinarily broad range of experiments, there exist a number of contending schools of thought over their interpretation.

Determinism To explain these properties, we need to be more explicit about the kind of picture an interpretation provides. To that end we will regard an interpretation as a correspondence between the elements of the mathematical formalism M and the elements of an interpreting structure I, where: The mathematical formalism M consists of the Hilbert space machinery of ket-vectors , self-adjoint operators acting on the space of ket-vectors, unitary time dependence of the ket-vectors, and measurement operations. In this context a measurement operation is a transformation which turns a ket-vector into a probability distribution for a formalization of this concept see quantum operations. The interpreting structure I includes states, transitions between states, measurement operations, and possibly information about spatial extension of these elements. A measurement operation refers to an operation which returns a value and might result in a system state change. Spatial information would be exhibited by states represented as functions on configuration space. The transitions may be non-deterministic or probabilistic or there may be infinitely many states. The crucial aspect of an interpretation is whether the elements of I are regarded as physically real. Hence the bare instrumentalist view of quantum mechanics outlined in the previous section is not an interpretation at all, for it makes no claims about elements of physical reality. The current usage of realism and completeness originated in the paper in which Einstein and others proposed the EPR paradox. They characterised element of reality as a quantity whose value can be predicted with certainty before measuring or otherwise disturbing it, and defined a complete physical theory as one in which every element of physical reality is accounted for by the theory. In a semantic view of interpretation, an interpretation is complete if every element of the interpreting structure is present in the mathematics. Realism is also a property of each of the elements of the maths; an element is real if it corresponds to something in the interpreting structure. For example, in some interpretations of quantum mechanics such as the many-worlds interpretation the ket vector associated to the system state is said to correspond to an element of physical reality, while in other interpretations it is not. Determinism is a property characterizing state changes due to the passage of time, namely that the state at a future instant is a function of the state in the present see time evolution. It may not always be clear whether a particular interpretation is deterministic or not, as there may not be a clear choice of a time parameter. Moreover, a given theory may have two interpretations, one of which is deterministic and the other not. Local realism has two aspects: The value returned by a measurement corresponds to the value of some function in the state space. In other words, that value is an element of reality; The effects of measurement have a propagation speed not exceeding some universal limit e. In order for this to make sense, measurement operations in the interpreting structure must be localized. A precise formulation of local realism in terms of a local hidden-variable theory was proposed by John Bell. Copenhagen interpretation The Copenhagen interpretation is the "standard" interpretation of quantum mechanics formulated by Niels Bohr and Werner Heisenberg while collaborating in Copenhagen around Bohr and Heisenberg extended the probabilistic interpretation of the wavefunction proposed originally by Max Born. The Copenhagen interpretation rejects questions like "where was the particle before I measured its position? According to the interpretation, the interaction of an observer or apparatus that is external to the quantum system is the cause of wave function collapse, thus according to Paul Davies , "reality is in the observations, not in the electron". Many-worlds interpretation The many-worlds interpretation is an interpretation of quantum mechanics in which a universal wavefunction obeys the same deterministic, reversible laws at all times; in particular there is no indeterministic and irreversible wavefunction collapse associated with measurement. The phenomena associated with measurement are claimed to be explained by decoherence , which occurs when states interact with the environment producing entanglement , repeatedly "splitting" the universe into mutually unobservable alternate historiesâ€"effectively distinct universes within a greater multiverse. Consistent histories The consistent histories interpretation generalizes the conventional Copenhagen interpretation and attempts to provide a natural interpretation of quantum cosmology. The theory is based on a consistency criterion that allows the history of a system to be described so that the probabilities for each history obey the additive rules of classical probability. According to this interpretation, the purpose of a quantum-mechanical theory is to predict the relative probabilities of various alternative histories for example, of a particle. Ensemble interpretation The ensemble interpretation , also called the statistical interpretation, can be viewed as a minimalist interpretation. That is, it claims to make the fewest assumptions associated with the standard mathematics. It takes the statistical interpretation of Born to the fullest extent. Probably the most notable supporter of such an interpretation was Einstein: The attempt to conceive the quantum-theoretical description as the complete description of the individual systems leads to unnatural theoretical interpretations, which become immediately unnecessary if one accepts the interpretation that the description refers to ensembles of systems and not to individual systems. A new version of the ensemble interpretation that relies on a reformulation of probability theory was introduced by Raed Shaiia. De Broglieâ€"Bohm theory The de Broglieâ€"Bohm theory of quantum mechanics also known as the pilot wave theory is a theory by Louis de Broglie and extended later by David Bohm to include measurements. Particles, which always have positions, are guided by the wavefunction. The theory takes place in a single space-time, is non-local , and is deterministic. The measurement problem is resolved, since the particles have definite positions at all times. Relational quantum mechanics The essential idea behind relational quantum mechanics , following the precedent of special relativity , is that different observers may give different accounts of the same series of events: Consequently, if quantum mechanics is to be a complete theory, relational quantum mechanics argues that the notion of "state" describes not the observed system itself, but the relationship, or correlation, between the system and its observer s. The state vector of conventional quantum mechanics becomes a description of the correlation of some degrees of freedom in the observer, with respect to the observed system. However, it is held by relational quantum mechanics that this applies to all physical objects, whether or not they are conscious or macroscopic. Any "measurement event" is seen simply as an ordinary physical interaction, an establishment of the sort of correlation discussed above. Thus the physical content of the theory has to do not with objects themselves, but the relations between them. Cramer is an interpretation of quantum mechanics inspired by the Wheelerâ€"Feynman absorber theory. This interpretation of quantum mechanics is unique in that it not only views the wave function as a real entity, but the complex conjugate of the wave function, which appears in the Born rule for calculating the expected value for an observable, as also real. More recent work on the stochastic interpretation has been done by M. Objective collapse theories[edit] Main article: Objective collapse theory Objective collapse theories differ from the Copenhagen interpretation by regarding both the wave function and the process of collapse as ontologically objective meaning these exist and occur independent of the observer. In objective theories, collapse occurs either randomly "spontaneous localization" or when some physical threshold is reached, with observers having no special role. Thus, objective-collapse theories are realistic, indeterministic, no-hidden-variables theories. Standard quantum mechanics does not specify any mechanism of collapse; QM would need to be extended if objective collapse is correct. The requirement for an extension to QM means that objective collapse is more of a theory than an interpretation.

Chapter 2 : Modal Interpretations of Quantum Mechanics (Stanford Encyclopedia of Philosophy)

The "Copenhagen Interpretation" is the oldest and one of the best-known interpretations of quantum physics, and an example of what are known as "collapse" interpretations.

Introduction The fundamental idea of the MWI, going back to Everett , is that there are myriads of worlds in the Universe in addition to the world we are aware of. In particular, every time a quantum experiment with different possible outcomes is performed, all outcomes are obtained, each in a different world, even if we are only aware of the world with the outcome we have seen. In fact, quantum experiments take place everywhere and very often, not just in physics laboratories: The MWI consists of two parts: A mathematical theory which yields the time evolution of the quantum state of the single Universe. A prescription which sets up a correspondence between the quantum state of the Universe and our experiences. It is a rigorous mathematical theory and is not problematic philosophically. An additional difficulty in setting up ii follows from the fact that human languages were developed at a time when people did not suspect the existence of parallel worlds. The mathematical part of the MWI, i , yields less than mathematical parts of some other theories such as, e. In contrast, in Bohmian mechanics the mathematical part yields almost everything, and the analog of ii is very simple: The Bohmian positions of all particles yield the familiar picture of the single world we are aware of. Thus, philosophically, a theory like Bohmian mechanics achieves more than the MWI, but at the price of adding the non-local dynamics of Bohmian particle positions. A world is the totality of macroscopic objects: I will call it a centered world. This concept is useful when a world is centered on a perceptual state of a sentient being. In this world, all objects which the sentient being perceives have definite states, but objects that are not under observation might be in a superposition of different classical states. The advantage of a centered world is that a quantum phenomenon in a distant galaxy does not split it, while the advantage of the definition presented here is that we can consider a world without specifying a center, and in particular our usual language is just as useful for describing worlds that existed at times when there were no sentient beings. Obviously, the definition of the world as everything that exists does not hold in the MWI. The Universe incorporates many worlds similar to the one the layman is familiar with. A layman believes that our present world has a unique past and future. According to the MWI, a world defined at some moment of time corresponds to a unique world at a time in the past, but to a multitude of worlds at a time in the future. I have a particular, well defined past: In the framework of the MWI it is meaningless to ask: Which Lev in will I be? I will correspond to them all. Every time I perform a quantum experiment with several possible results it only seems to me that I obtain a single definite result. Indeed, Lev who obtains this particular result thinks this way. However, this Lev cannot be identified as the only Lev after the experiment. Although this approach to the concept of personal identity seems somewhat unusual, it is plausible in the light of the critique of personal identity by Parfit Parfit considers some artificial situations in which a person splits into several copies, and argues that there is no good answer to the question: Which copy is me? He concludes that personal identity is not what matters when I divide. Saunders and Wallace a argue that based on the semantics of Lewis one can find a meaning for this question. Correspondence Between the Formalism and Our Experience We should not expect to have a detailed and complete explanation of our experience in terms of the wave function of particles that we and our immediate environment are made of. We just have to be able to draw a basic picture which is free of paradoxes. A sketch of the connection between the wave function of the Universe and our experience follows. Elementary particles of the same kind are identical. Therefore, the essence of an object is the quantum state of its particles and not the particles themselves see the elaborate discussion in the entry on identity and individuality in quantum theory: Clearly, we cannot now write down an exact wave function of a cat. We know, to a reasonable approximation, the wave function of some elementary particles that constitute a nucleon. The wave function of the electrons and the nucleons that together make up an atom is known with even better precision. The wave functions of molecules i. A lot is known about biological cells, so physicists can write down a rough form of the quantum state of a cell. Out of cells we construct various tissues and then the whole body of a cat or a table. According to the definition of a world we have adopted, in each world the cat is in a definite state: Formally, the quantum state of an object which consists of N particles is defined in 3N dimensional configuration space. However, in order to make a connection to our experience it is crucial to understand the quantum state as an entangled wave function of N particles in 3 dimensional space. Physical interactions are local in 3 dimensions and we only experience objects defined in 3-space. The density of the wave function of molecules of the macroscopic object in 3-space is the bridge between the wave function of the object and our experience of that object. This concept, which is a property of the wave function only, plays the role of the primitive ontology present in other interpretations of quantum mechanics, Allori et al. There might be some entanglement between weakly coupled variables like nuclear spins belonging to different objects. Consider a text-book description of quantum measurements based on the von Neumann approach according to which each quantum measurement ends up with the collapse of the wave function to the eigenstate of the measured variable. The quantum measurement device must be a macroscopic object with macroscopically different states corresponding to different outcomes. In this case, the MWI all-particles wave function corresponding to a world with a particular outcome is the same as in the von Neumann theory provided there is a collapse to the wave function with this outcome. Von Neumann analysis helps in understanding the correspondence between the wave function and our perception of the world. However, as Becker explains, the status of the wave function for von Neumann is not ontological as in the MWI described here, but epistemic: In most situations, only macroscopic objects are relevant to our experience. In such situations a description of a world with states of only macroscopic objects, such as sources and detectors, is possible but cumbersome. Hence it is fruitful to add a description of microscopic objects. Vaidman argues that the proper way to describe the relevant microscopic particles is by the two-state vector which consists of the usual, forward evolving state specified by the measurement in the past and a backward evolving state specified by the measurement in the future. Such a description provides a simple explanation of the weak trace the particles leave, Vaidman The quantum state of the Universe can be decomposed into a superposition of terms corresponding to different worlds: Different classically described states correspond to orthogonal quantum states. Therefore, different worlds correspond to orthogonal states: Indeed, the concept of an object itself has no rigorous definition: If the displacement is much smaller than the quantum uncertainty, it must be considered to be in the same place, because in this case the quantum state of the cat is almost the same and the displacement is undetectable in principle. But this is only an absolute bound, because our ability to distinguish various locations of the cat is far from this quantum limit. Furthermore, the state of an object e. In our construction, however, the quantum state of an object is defined at a particular time. In fact, we have to ensure that the quantum state will have the shape of the object not only at that time, but for some period of time. Splitting of the world during this period of time is another source of ambiguity because there is no precise definition of when the splitting occurs. The time of splitting corresponds to the time of the collapse in the approach given by von Neumann He provided a very extensive discussion showing that it does not matter when exactly the collapse occurs, and this analysis shows also that it does not matter when the splitting in the MWI occurs. The concepts we use: Since it is not enough for a physical theory to be just fine FAPP, a quantum mechanics needs rigorous foundations. In the alternative approach, the basis of a centered world is defined directly by an observer. Therefore, given the nature of the observer and her concepts for describing the world, the particular choice of the decomposition 2 follows up to a precision which is good FAPP, as required. If we do not ask why we are what we are, and why the world we perceive is what it is, but only how we can explain relations between the events we observe in our world, then the problem of the preferred basis does not arise: But if we do ask why we are what we are, we can explain more. Looking at the details of the physical world, the structure of the Hamiltonian, the value of the Planck constant, etc. The main argument is that the locality of interactions yields stability of worlds in which objects are well localized. The small value of the Planck constant allows macroscopic objects to be well localized for a long period of time. This is the phenomenon of decoherence which has attracted enormous attention in recent years, e. I describe this property as the measure of existence of a world. The measure of existence of a world quantifies its ability to interfere with other worlds in a gedanken experiment, see Vaidman p. The measure of existence is the parallel of the probability measure discussed in Everett and pictorially described in Lockwood p. It can also be expressed as the expectation value of Pi, the projection operator on the space of quantum states corresponding to the actual values of all physical variables describing the world i: It is the sum of the measures of existence of all different worlds in which I exist; it can also be defined as the measure of existence of my perception world. Note that I do not directly experience the measure of my existence. I feel the same weight, see the same brightness, etc. However, even if there is no probability in the MWI, it is possible to explain our illusion of apparent probabilistic events. Due to the identity of the mathematical counterparts of worlds, we should not expect any difference between our experience in a particular world of the MWI and the experience in a single-world universe with collapse at every quantum measurement. The quantum state of the Universe at one time specifies the quantum state at all times. It is senseless to ask: To solve this difficulty, Albert and Loewer proposed the Many Minds interpretation in which the different worlds are only in the minds of sentient beings. In addition to the quantum wave of the Universe, Albert and Loewer postulate that every sentient being has a continuum of minds. Whenever the quantum wave of the Universe develops into a superposition containing states of a sentient being corresponding to different perceptions, the minds of this sentient being evolve randomly and independently to mental states corresponding to these different states of perception with probabilities equal to the quantum probabilities for these states. Since there is a continuum of minds, there will always be an infinity of minds in any sentient being and the procedure can continue indefinitely. This resolves the difficulty:

Chapter 3 : calendrierdelascience.com: Interpretation of quantum mechanics

Presenting a realistic interpretation of quantum mechanics and, in particular, a realistic view of quantum waves, this book defends, with one exception, Schrodinger's views on quantum mechanics. Johansson goes on to defend the view that the collapse of a wave function during a measurement is a real physical collapse of a wave and argues that.

References and Further Reading 1. The Development of Quantum Mechanics Quantum mechanics was developed in the early twentieth century in response to several puzzles concerning the predictions of classical preth century physics. Classical electrodynamics, while successful at describing a large number of phenomena, yields the absurd conclusion that the electromagnetic energy in a hollow cavity is infinite. It also predicts that the energy of electrons emitted from a metal via the photoelectric effect should be proportional to the intensity of the incident light, whereas in fact the energy of the electrons depends only on the frequency of the incident light. Taken together with the prevailing account of atoms as clouds of positive charge containing tiny negatively charged particles electrons , classical mechanics entails that alpha particles fired at a thin gold foil should all pass straight through, whereas in fact a small proportion of them are reflected back towards the source. In response to the first puzzle, Max Planck suggested in that light can only be emitted or absorbed in integral units of hn, where n is the frequency of the light and h is a constant. This is the hypothesis that energy is quantizedâ€”that it is a discrete rather than continuous quantityâ€”from which quantum mechanics takes its name. This hypothesis can be used to explain the finite quantity of electromagnetic energy in a hollow cavity. In Albert Einstein proposed that the quantization of energy can solve the second puzzle too; the minimum amount of energy that can be transferred to an electron from the incident light is hn, and hence the energy of the emitted electrons is proportional to the frequency of the light. Again, energy is quantized. The model has the additional benefit of explaining the spectrum of light emitted from excited atoms; since only certain energies are allowed, only certain wavelengths of light are possible when electrons jump between these levels, and this explains why the spectrum of the light consists of discrete wavelengths rather than a continuum of possible wavelengths. But the quantization of energy raises as many questions as it answers. Why are only certain energies allowed? What prevents the electrons in an atom from losing energy continuously and spiraling in towards the nucleus, as classical physics predicts? In Louis de Broglie suggested that electrons are wave-like rather than particle-like, and that the reason only certain electron energies are allowed is that energy is a function of wavelength, and only certain wavelengths can fit without remainder in the electron orbit for a given energy. This theory has been astonishingly successful. This success has continued. Quantum mechanics in the form of quantum electrodynamics correctly predicts the magnetic moment of the electron to an accuracy of about one part in a trillion, making it the most accurate theory in the history of science. And so far its predictive track record is perfect: But on a descriptive and explanatory level, the theory of quantum mechanics is less than satisfactory. Typically when a new theory is introduced, its proponents are clear about the physical ontology presupposedâ€”the kind of objects governed by the theory. Superficially, quantum mechanics is no different, since it governs the evolution of waves through space. But there are at least two reasons why taking these waves as genuine physical entities is problematic. First, although in the case of electron interference the number of electrons arriving at a particular location can be explained in terms of the propagation of waves though the apparatus, each electron is detected as a particle with a precise location, not as a spread-out wave. As Max Born noticed in , the intensity squared amplitude of the quantum wave at a location gives the probability that the particle is located there; this is the Born rule for assigning probabilities to measurement outcomes. The second reason to doubt the reality of quantum waves is that the quantum waves do not propagate through ordinary three-dimensional space, but though a space of 3n dimensions, where n is the number of particles in the system concerned. Hence it is not at all clear that the underlying ontology is genuinely of waves propagating through space. Indeed, the standard terminology is to call the quantum mechanical representation of the state of a system a wavefunction rather than a wave, perhaps indicating a lack of metaphysical commitment: So quantum mechanics is a phenomenally successful theory, but it is not at all clear what, if anything, it tells us about the underlying nature of the physical world. Quantum mechanics, perhaps uniquely among physical theories, stands in need of an interpretation to tell us what it means. Four kinds of interpretation are described in detail below and some others more briefly. The first twoâ€”the Copenhagen interpretation and the many-worlds interpretationâ€”take standard quantum mechanics as their starting point. The third and fourthâ€”hidden variable theories and spontaneous collapse theoriesâ€”start by modifying the theory of quantum mechanics, and hence are perhaps better described as proposals for replacing quantum mechanics with a closely related theory. The Copenhagen Interpretation The earliest consensus concerning the meaning of quantum mechanics formed around the work of Niels Bohr and Werner Heisenberg in Copenhagen during the s, and hence became known as the Copenhagen interpretation. Rather, quantum mechanics is an extremely effective tool for predicting measurement results that takes the configuration of the measuring apparatus described classically as input, and produces probabilities for the possible measurement outcomes described classically as output. It is sometimes claimed that the Copenhagen interpretation is a product of the logical positivism that flourished in Europe during the same period. The logical positivists held that the meaningful content of a scientific theory is exhausted by its empirical predictions; any further speculation into the nature of the world that produces these measurement outcomes is quite literally meaningless. This certainly has some resonances with the Copenhagen interpretation, particularly as described by Heisenberg. However, Bohr thinks we can say little else about the micro-world. Bohr, like Kant, thinks that we can only conceive of things in certain ways, and that the world as it is in itself is not amenable to such conceptualization. If this is correct, it is inevitable that our fundamental physical theories are unable to describe the world as it is, and the fact that we can make no sense of quantum mechanics as a description of the world should not concern us. However, the motivation for adopting a Copenhagen-style interpretation can be made independent of any overarching philosophical position. Since the intensity of the wavefunction at a location gives the probability of the particle occupying that location, it is natural to regard the wavefunction as a reflection of our knowledge of the system rather than a description of the system itself. This view, held by Einstein, suggests that quantum mechanics is incomplete, since it gives us only an instrumental recipe for calculating the probabilities of outcomes, rather than a description of the underlying state of the system that gives rise to those probabilities. But it was later proved as we shall see that given certain plausible assumptions, it is impossible to construct such a description of the underlying state. However, the Copenhagen interpretation has at least two major drawbacks. First, a good deal of the early evidence for quantum mechanics comes from its ability to explain the results of interference experiments involving particles like electrons. His proposal was to take quantum mechanics as descriptive and universal; the quantum state is a genuine description of the physical system concerned, and macroscopic systems are just as well described in this way as microscopic ones. An immediate problem facing such a realist interpretation of the quantum state is the provenance of the outcomes of quantum measurements. Recall that in the case of electron interference, what is detected is not a spread-out wave, but a particle with a well-defined location, where the wavefunction intensity at a location gives the probability that the particle is located there. How does Everett account for these facts? What he suggests is that we model the measurement process itself quantum mechanically. It is by no means uncontroversial that measuring devices and human observers admit of a quantum mechanical description, but given the assumption that quantum mechanics applies to all material objects, such a description ought to be available at least in principle. So consider for simplicity the situation in which the wavefunction intensity for the electron at the end of the experiment is non-zero in only two regions of space, A and B. The detectors at these locations can be modeled using a wavefunction too, with the result that the electron wavefunction component at A triggers a corresponding change in the wavefunction of the A-detector, and similarly at B. In the same way, we can model the experimenter who observes the detectors using a wavefunction, with the result that the change in the wavefunction of the A-detector causes a change in the wavefunction of the observer corresponding to seeing that the A-detector has fired, and the change in the wavefunction of the B-detector causes a change in the wavefunction of the observer corresponding to seeing that the B-detector has fired. In sum, the wave structure of the electron-detector-observer system consists of two distinct branches, the A-outcome branch and the B-outcome branch. Since these two branches are relatively causally isolated from each other, we can describe them as two distinct worlds, in one of which the electron hits the detector at A and the observer sees the A-detector fire, and in the other of which the electron hits the detector at B and the observer sees the B-detector fire. This talk of worlds needs to be treated carefully, though; there is just one physical world, described by the quantum state, but because observers along with all other physical objects exhibit this branching structure, it is as if the world is constantly splitting into multiple copies. It is not clear whether Everett himself endorsed this talk of worlds, but this is the understanding of his work that has become canonical; call it the many-worlds interpretation. According to the many-worlds interpretation, then, every physically possible outcome of a measurement actually occurs in some branch of the quantum state, but as an inhabitant of a particular branch of the state, a particular observer only sees one outcome. This explains why, in the electron interference experiment, the outcome looks like a discrete particle even though the object that passes through the interference device is a wave; each point in the wave generates its own branch of reality when it hits the detectors, so from within each of the resulting branches it looks like the incoming object was a particle. The main advantage of the many-worlds interpretation is that it is a realist interpretation that takes the physics of standard quantum mechanics literally. It is often met with incredulity, since it entails that people along with other objects are constantly branching into innumerable copies, but this by itself is no argument against it. Still, the branching of people leads to philosophical difficulties concerning identity and probability, and these particularly the latter constitute genuine difficulties facing the approach. The problem of identity is a philosophically familiar one: Various solutions have been developed in the literature. One might follow Derek Parfit and bite the bullet here: Or one might follow David Lewis and rescue strict identity by stipulating that a person is a four-dimensional history rather than a three dimensional object. According to this picture, there are two people two complete histories present both before and after the fission event; they initially overlap but later diverge. Identity over time is preserved, since each of the pre-split people is identical with exactly one of the post-split people. Both of these positions have been proposed as potential solutions to the problem of personal identity in a many-worlds universe. A third solution that is sometimes mentioned is to stipulate that a person is the whole of the branching entity, so that the pre-split person is identical to both her successors, and despite our initial intuition otherwise the successors are identical to each other. So the problem of identity admits of a number of possible solutions, and the only question is how one should try to decide between them. Indeed, one might argue that there is no need to decide between them, since the choice is a pragmatic one about the most useful language to use to describe branching persons. The problem of probability, though, is potentially more serious. As noted above, quantum mechanics makes its predictions in the form of probabilities: The striking agreement of the observed distribution of outcomes with these probabilities is what underwrites our confidence in quantum mechanics. But according to the many-worlds interpretation, every outcome of a measurement actually occurs in some branch of reality, and the well-informed observer knows this. It is hard to see how to square this with the concept of probability; at first glance, it looks like every outcome has probability 1, both objectively and epistemically. In particular, if a measurement results in two branches, one with a large squared amplitude and one with a small squared amplitude, it is hard to see why we should regard the former as more probable than the latter. But unless we can do so, the empirical success of quantum mechanics evaporates. It is worth noting, however, that the foundations of probability are poorly understood. When we roll two dice, the chance of rolling 7 is higher than the chance of rolling But there is no consensus concerning the meaning of chance claims, or concerning why the higher chance of 7 should constrain our expectations or behavior. So perhaps a quantum branching world is in no worse shape than a classical linear world when it comes to understanding probability. We may not understand how squared wavefunction amplitude could function as chance in guiding our expectations, but perhaps that is no barrier to postulating that it does so function. A more positive approach has been developed by David Deutsch and David Wallace, arguing that given some plausible constraints on rational behavior, rational individuals should behave as if squared wavefunction amplitudes are chances. If one combines this with a functionalist attitude towards chanceâ€”that whatever functions as chance in guiding behavior is chanceâ€”then this program promises to underwrite the contention that squared wave amplitudes are chances. However, the assumptions on which the Deutsch-Wallace argument is based can be challenged. In particular, they assume that it is irrational to care about branching per se: But it is not clear that this is a matter of rationality any more than the question of whether having several happy children is better than having one happy child. A further worry about the many-words theory that has been largely put to rest concerns the ontological status of the worlds. It has been argued that the postulation of many worlds is ontologically profligate. However, the current consensus is that worlds are emergent entities just like tables and chairs, and talk of worlds is just a convenient way of talking about the features of the quantum state. On this view, the many-worlds interpretation involves no entities over and above those represented by the quantum state, and as such is ontologically parsimonious. There remains the residual worry that the number of branches depends sensitively on mathematical choices about how to represent the quantum state. Wallace, however, embraces this indeterminacy, arguing that even though the many-worlds universe is a branching one, there is no well-defined number of branches that it has. If tenable, this goes some way towards resolving the above concern about the rationality of caring about branching per se:

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Chapter 4 : A Direct Experiential Interpretation of Quantum Mechanics - Kenneth Chan

The orthodox view of quantum mechanics, known as the "Copenhagen interpretation" after the home city of Danish physicist Niels Bohr, one of its architects, holds that particles play out all.

Now, two physicists have devised a modern version of the paradox by replacing the cat with a physicist doing experimentsâ€”with shocking implications. Quantum theory has a long history of thought experiments, and in most cases these are used to point to weaknesses in various interpretations of quantum mechanics. But the latest version, which involves multiple players, is unusual: This means that quantum theory contradicts itself. The conceptual experiment has been debated with gusto in physics circles for more than two yearsâ€”and has left most researchers stumped, even in a field accustomed to weird concepts. Frauchiger has now left academia. Weird world Quantum mechanics underlies nearly all of modern physics, explaining everything from the structure of atoms to why magnets stick to each other. But its conceptual foundations continue to leave researchers grasping for answers. Its equations cannot predict the exact outcome of a measurementâ€”for example, of the position of an electronâ€—only the probabilities that it can yield particular values. The most common way of understanding this was formulated in the s by quantum-theory pioneers Niels Bohr and Werner Heisenberg, and is called the Copenhagen interpretation, after the city where Bohr lived. The Copenhagen interpretation left open the question of why different rules should apply to the quantum world of the atom and the classical world of laboratory measurements and of everyday experience. But it was also reassuring: Now, Frauchiger and Renner are shaking physicists out of this comforting position. Their theoretical reasoning says that the basic Copenhagen pictureâ€—as well as other interpretations that share some of its basic assumptionsâ€—is not internally consistent. In that case, the state of the cat was uncertain until the experimenter opened the box and checked it. In , the Hungarian physicist Eugene Wigner proposed a version of the paradox in which he replaced the cat and the poison with a physicist friend who lived inside a box with a measuring device that could return one of two results, such as a coin showing heads or tails. One school of thought says that it does, suggesting that consciousness is outside the quantum realm. But if quantum mechanics applies to the physicist, then she should be in an uncertain state that combines both outcomes until Wigner opens the box. They have two Wigners, each doing an experiment on a physicist friend whom they keep in a box. One of the two friends call her Alice can toss a coin andâ€—using her knowledge of quantum physicsâ€—prepare a quantum message to send to the other friend call him Bob. When the two Wigners open their boxes, in some situations they can conclude with certainty which side the coin landed on, Renner saysâ€—but occasionally their conclusions are inconsistent. Yet it might be feasible to make two quantum computers play the parts of Alice and Bob: Quantum computers sophisticated enough to do this do not yet exist, Renner points out. Dueling interpretations Physicists are still coming to terms with the implications of the result. It has triggered heated responses from experts in the foundations of quantum theory, many of whom tend to be protective of their pet interpretation. And different researchers tend to draw different conclusions. Some interpretations of quantum mechanics already allow for views of reality that depend on perspective. That could be less unsavory than having to admit that quantum theory does not apply to complex things such as people, he says. Robert Spekkens, a theoretical physicist at the Perimeter Institute for Theoretical Physics in Waterloo, Canada, says that the way out of the paradox could hide in some subtle assumptions in the argument, in particular in the communication between Alice and Bob. But he admits that he has not found a solution yet. For now, physicists are likely to continue debating.

Chapter 5 : Interpretations of quantum mechanics - Wikipedia

The orthodox view of quantum mechanics, known as the "Copenhagen interpretation" after the home city of Danish physicist Niels Bohr, one of its architects, holds that particles play out all possible realities simultaneously.

Advertisement What is the ultimate nature of reality? Are quantum effects constantly carving us into innumerable copies, each copy inhabiting a different version of the universe? Or do all those other worlds pop out of existence as mere might-have-beens? Do our particles surf on quantum waves? Or are we ultimately made of the quantum waves alone? Or do the waves merely represent how much information we could possess about the state of the world? And if the waves are just a kind of information, information about what? Or is the information all that there isâ€"and all that we are? And although quantum mechanics is primarily the physics of the very smallâ€"of atoms, electrons, photons and other such particlesâ€"the world is made up of those particles. If their individual reality is radically different from what we imagine then surely so too is the reality of the pebbles, people and planets that they make up. As recounted by our December article, The Many Worlds of Hugh Everett by journalist Peter Byrne , 50 years ago the iconoclastic physics student Hugh Everett introduced the idea that quantum physics is incessantly splitting the universe into alternate branches. The basic scenario an interpretation must address is when a quantum system is prepared in a combination of states known as a superposition. The problem is that when we observe or measure a superposition, we get but one result: Copenhagen Interpretation This interpretation or variants of it has long been the party line for quantum physicists. After we detect it at A or B, we have to represent the particle with a new wave function that conforms with the measurement result. Everett argued that this approach was philosophically a mess: Also known as the relative state formulation. The superposition of the particle spreads to the apparatus, and to us looking at the apparatus, and ultimately to the entire universe. The components of the resulting superposition are like parallel universes: What bothers people about this interpretation is its conclusion that we are perpetually dividing into multiple copies, which may have ghastly implications as well as being bizarre. Bohmian Interpretation Also known as the De Broglieâ€"Bohm interpretation or the pilot wave interpretation. This theory postulates that every particle not only has a wave function but also exists as an actual particle riding along at some precise but unknown location on the wave and being guided by it. The randomness of quantum measurements comes about because we cannot know exactly where a particle started out. For example, Roger Penrose has proposed that gravitational effects may play this role. By differing from standard quantum theory, such models in principle might be falsifiable by experiment or conversely, standard theory could be falsified in their favor. Decoherence Theory This is not an interpretation, but it is an important element of the modern understanding of quantum mechanics. It expands upon the kind of mathematical analysis that led Everett to his interpretation, because it analyzes the effect that stray quantum interactions with the surrounding environment have on a system in a superposition. It explains very well why we see the classical world that we do, and clarifies the requirements to keep quantum effects manifest in the lab. Copenhagenists can point to decoherence as an explanation of what makes large classical systems different from small quantum systems in general, large systems decohere much more readily and rapidly than tiny ones. Everettians can point to it as a more complete explanation of how the parallel branches form and become independent. But best of all, decoherence can be studied experimentally, and a very active area of quantum research is confirming it and exploring it in ever greater detail. In some respects the decision between a Copenhagenist and an Everettian viewpoint boils down to a basic question: Is the wave function real or is it just information? Imagine the standard classical scenario of flipping a coin. These include energy levels of atoms; predictions for particle collider experiments; the properties of semiconductors, superconductors and other materials; and so on. It is all that most physicists ever need. Transactional Interpretation This interpretation has waves traveling forward and backward in time, setting up standing waves, for example between an emitter of a particle and its subsequent detector. It was proposed by John G. These insights have led Cramer to pursue an experiment to try to demonstrate the sending of signals backward in time which most quantum physicists will tell you is impossible if standard quantum mechanics is correct.

Chapter 6 : Interpreting Quantum Entanglement: Steps Towards Coherentist Quantum Mechanics - Philsci

Foundations and Interpretation of Quantum Mechanics: In the Light of a Critical-Historical Analysis of the Problems and of a Synthesis of the Results Jun by Gennaro Auletta and Giorgio Parisi.

However, this postulate leads to many difficulties: What causes this discontinuous change in the physical state of a system? The postulate is especially worrying when applied to entangled compound systems whose components are well-separated in space. For example, in the Einstein-Podolsky-Rosen EPR experiment there are strict correlations between two systems that have interacted in the past, in spite of the fact that the correlated quantities are not sharply defined in the individual systems. The projection postulate in this case implies that the collapse resulting from a measurement on one of the systems instantaneously defines a sharp property in the distant other system. See the discussion of the collapse or projection postulate in the entry on philosophical issues in quantum theory. A possible way clear of these problems was noticed by van Fraassen , , , who proposed to eliminate the projection postulate from the theory. The dynamical state determines what may be the case: The dynamical state is just the quantum state of the ordinary textbook approach a vector or density matrix in Hilbert space. The value state is typically different from the dynamical state. The general idea of this original proposal, and of modal interpretations in general, is that physical systems at all times possess a number of well-defined physical properties, i. Which physical quantities are sharply defined, and which values they take, may change in time. Empirical adequacy of course requires that the dynamical state generate the correct Born frequencies of observable quantities. An essential feature of this approach is that a system may have a sharp value of an observable even if the dynamical state is not an eigenstate of that same observable. In the value state terminology, the eigenstate-eigenvalue link would say that a system has the value state corresponding to a given eigenvalue of a given observable if and only if its dynamical state is an eigenstate of the observable corresponding to that eigenvalue. Van Fraassen stipulates the following restriction: In other words, the non-commutativity of observables imposes limits not on our knowledge about the properties of a system, but rather on the possibility of joint existence of properties, independently of our knowledge. Non-commuting quantities, like position and momentum, cannot jointly be well-defined quantities of a physical system. Empirical adequacy requires that, in cases of measurement, the after-measurement value state of the apparatus corresponds to the definite measurement result. Therefore, in these cases one would expect the dynamical state to generate a probability measure over exactly the set of possible measurement results. Indeed, the dynamical state in general only tells us what is possible. General features of modal interpretations In the s several authors presented realist interpretations which, in retrospect, can be regarded as elaborations or variations on the just-mentioned modal themes for an overview and references, see Dieks and Vermaas In spite of the differences among them, all the modal interpretations agree on the following points: The interpretation should be based on the standard formalism of quantum mechanics, with one exception: Quantum mechanics is taken to be fundamental: The dynamical state of the system pure or mixed tells us what the possible properties of the system and their corresponding probabilities are. This is achieved by a precise mathematical rule that specifies a probabilistic relationship between the dynamical state and possible value states. A quantum measurement is an ordinary physical interaction. There is no collapse of the dynamical state the wavefunction: The Kochen-Specker theorem is a barrier to any realist classical-like interpretation of quantum mechanics, since it proves the impossibility of ascribing precise values to all physical quantities observables of a quantum system simultaneously, while preserving the functional relations between commuting observables. See the entry on the the Kochen-Specker theorem. Therefore, realist non-collapse interpretations are committed to selecting a privileged set of definite-valued observables out of all observables. Since the mids a series of approaches faced this question Clifton a,b; Dickson a,b; Dieks The common result was that the possible value states of the components of a two-part composite system are given by the states occurring in the Schmidt bi-orthogonal decomposition of the dynamical state, or, equivalently, by the projectors occurring in the spectral decomposition of the density matrices representing partial systems obtained by partial tracing â€”see Section 4 for more details. On this basis, Bub , , suggests that with hindsight a number of traditional interpretations of quantum theory can be characterized as modal interpretations. If one supposes that each factorization defines a legitimate set of subsystems of the universe, the multiple factorizability implies that there exists a multiplicity of ways of defining the building blocks of nature. If the properties value states of all these quantum systems are defined by means of the partial trace with respect to the rest of the universe see later for more details , it turns out that a contradiction of the Kochen-Specker type arises Bacciagaluppi The property ascription to the atomic quantum systems in the AMI further follows the general idea of modal interpretations, that is, the ascription depends via a fixed rule on the dynamical state of the system. The main challenge for the AMI is to justify the assumption that there is a preferred partition of the universe and to provide some idea about what this factorization should look like. AMI also faces a conceptual problem. Two answers to this conceptual difficulty have been proposed. The first allows the existence of dispositional properties in addition to ordinary properties Clifton In other words, the composite quantum system, when interacting with its environment, can behave as a collective entity, screening off the contribution of the atomic quantum systems. In quantum mechanics the theorem means that, given a composite system consisting of two subsystems, its state picks out in many cases, uniquely a basis for each of the subsystems. According to the BDMI, those bases generate the definite-valued properties the value states of the corresponding subsystems. The BDMI is particularly appropriate to account for quantum measurement. Therefore, the pointer position is a definite-valued property of the apparatus: And analogously in the measured system: In spite of the fact that this modal interpretation is characterized by the central role played by biorthogonal decomposition, two different versions can be distinguished. One of them adopts a metaphysics in which all properties are relational and, as a consequence, the fact that the application of the interpretation is restricted to subsystems of a two-component compound system is not a problem Kochen Consider the measurement described above: By contrast, according to the other version Dieks , a,b the properties ascribed to the system do not have a relational character. This proposal therefore faces consistency questions about the assignments of definite values to observables according to different ways of splitting up the total system into components. This problem has been addressed by different authors during the s see Vermaas ; Bacciagaluppi The SDMI is based on the spectral decomposition of the reduced density operator: The SDMI also has a direct application to the measurement situation. Are we to apply the SDMI to each such factorization? How are the results related, if at all? Healey was also among the first to make use of the biorthogonal decomposition theorem, developing these ideas in a somewhat different direction. His main concern was the apparent non-locality of quantum mechanics. The first is consistency: A second is to maintain a plausible theory of the relationship between composite systems and their subsystems. A third is to maintain a plausible account of the relations among definite-valued properties at a given time. A fourth is to maintain a plausible account of the relations among definite-valued properties at different times. The structure of definite-valued properties that emerges from these conditions is extremely complicated. However, ideal measurement is a situation that can never be achieved in practice: Two kinds of non-ideal measurements are usually distinguished in the literature: Imperfect measurements pose a challenge to the BDMI and the SDMI, since their rules for selecting the definite-valued properties do not pick out the right properties for the apparatus in the imperfect case see Albert and Loewer , , ; also Ruetsche An example that clearly brings out the difficulties introduced by non-ideal measurements was formulated in the context of Stern-Gerlach experiments Elby In this case, in which the definite-valued properties selected by a modal interpretation are different from those expected, the question arises how different they are. There is another important problem related to non-ideal measurements. In fact, the observables so selected may be incompatible non-commuting with the observables that we expect on the basis of observation Bacciagaluppi and Hemmo , In order to face the problems that non-ideal measurements pose to the BDMI and the SDMI, several authors have appealed to the phenomenon of decoherence; this will be discussed below. The question is then: The answer to this question is negative: Moreover, he argues that the examples developed by Arntzenius and Clifton sound bizarre precisely in the light of Property Composition and Property Decomposition. But in the quantum realm we must accept that the questions of which properties are possessed by a system and which by its subsystems are different questions: Dynamics of properties As we have seen, modal interpretations intend to provide, for every instant, a set of definite-valued properties and their probabilities. Some advocates of modal interpretations may be willing to leave the matter, more or less, at that. Others take it to be crucial for any modal interpretation that it also answers questions of the form: In other words, they want a dynamics of actual properties. There are arguments on both sides. Those who argue for the necessity of such a dynamics maintain that we have to assure that the trajectories of actual properties really are, at least for macroscopic objects, like we see them to be, i. For example, we should require not only that the book at rest on the desk possess a definite location, but also that, if undisturbed, its location relative to the desk does not change in time. Accordingly, one cannot get away with simply specifying the definite properties at each instant of time. We need also to show that this specification is at least compatible with a reasonable dynamics; better still, specify this dynamics explicitly. Those who consider a dynamics of actual properties to be superfluous reply that such a dynamics is more than what an interpretation of quantum mechanics needs to provide. Memory contents for each instant are enough to make empirical adequacy possible. As pointed out by Ruetsche , in this debate about the need for a dynamics of actual properties it is important whether the modal interpretation is viewed as leading to a hidden-variables theory, in which value states are added as hidden variables to the original formalism in order to obtain a full description of the physical situation, or rather as only equipping the original formalism with a new semantics. In the first approach one would expect a full dynamics of actual properties, in the second this is not so clear. Of course, modal interpretations do admit a trivial dynamics, namely, one in which there is no correlation from one time to the next. However, this dynamics is unlikely to interest those who feel the need for a dynamics at all. Several researchers have contributed to the project of constructing a more interesting form of dynamics for modal interpretations see Vermaas , An important account is due to Bacciagaluppi and Dickson , see also Bacciagaluppi That work shows the most significant challenges that the construction of a dynamics of actual properties must face. However, in general this is not the case: Of course, one hopes to do so in a way that is not completely ad hoc. This result suggests a natural family of maps as discussed above: The second challenge to the construction of a dynamics arises from the fact that one wants to define transition probabilities over infinitesimal units of time, and then derive the finite-time transition probabilities from them.

DOWNLOAD PDF INTERPRETING QUANTUM MECHANICS

Chapter 7 : Interpretations of quantum mechanics - Wikiquote

The Many-Worlds Interpretation (MWI) of quantum mechanics holds that there are many worlds which exist in parallel at the same space and time as our own.

Bring fact-checked results to the top of your browser search. The interpretation of quantum mechanics Although quantum mechanics has been applied to problems in physics with great success, some of its ideas seem strange. A few of their implications are considered here. The intensity oscillates because of interference between the light waves emerging from the two slits, the rate of oscillation depending on the wavelength of the light and the separation of the slits. The oscillation creates a fringe pattern of alternating light and dark bands that is modulated by the diffraction pattern from each slit. If one of the slits is covered, the interference fringes disappear, and only the diffraction pattern shown as a broken line in Figure 5B is observed. A Monochromatic light incident on a pair of slits gives interference fringes alternate light and dark bands on a screen, B variation in the intensity of the light at the screen when both slits are open. With a single slit, there is no interference pattern; the intensity variation is shown by the broken line. As with Figure 4B, the same diagram would give the variation in the intensity of electrons in the corresponding electron experiment. The screen in the optical experiment is replaced by a closely spaced grid of electron detectors. There are many devices for detecting electrons; the most common are scintillators. When an electron passes through a scintillating material, such as sodium iodide, the material produces a light flash which gives a voltage pulse that can be amplified and recorded. The pattern of electrons recorded by each detector is the same as that predicted for waves with wavelengths given by the de Broglie formula. Thus, the experiment provides conclusive evidence for the wave behaviour of electrons. If the experiment is repeated with a very weak source of electrons so that only one electron passes through the slits, a single detector registers the arrival of an electron. This is a well-localized event characteristic of a particle. Each time the experiment is repeated, one electron passes through the slits and is detected. A graph plotted with detector position along one axis and the number of electrons along the other looks exactly like the oscillating interference pattern in Figure 5B. Thus, the intensity function in the figure is proportional to the probability of the electron moving in a particular direction after it has passed through the slits. If one of the slits is covered, the fringe pattern disappears and is replaced by the diffraction pattern for a single slit. Thus, both slits are needed to produce the fringe pattern. However, if the electron is a particle, it seems reasonable to suppose that it passed through only one of the slits. The apparatus can be modified to ascertain which slit by placing a thin wire loop around each slit. When an electron passes through a loop, it generates a small electric signal, showing which slit it passed through. However, the interference fringe pattern then disappears, and the single-slit diffraction pattern returns. Since both slits are needed for the interference pattern to appear and since it is impossible to know which slit the electron passed through without destroying that pattern, one is forced to the conclusion that the electron goes through both slits at the same time. In summary, the experiment shows both the wave and particle properties of the electron. The wave property predicts the probability of direction of travel before the electron is detected; on the other hand, the fact that the electron is detected in a particular place shows that it has particle properties. Therefore, the answer to the question whether the electron is a wave or a particle is that it is neither. It is an object exhibiting either wave or particle properties, depending on the type of measurement that is made on it. In other words, one cannot talk about the intrinsic properties of an electron; instead, one must consider the properties of the electron and measuring apparatus together. Hidden variables A fundamental concept in quantum mechanics is that of randomness , or indeterminacy. In general, the theory predicts only the probability of a certain result. Consider the case of radioactivity. Imagine a box of atoms with identical nuclei that can undergo decay with the emission of an alpha particle. In a given time interval, a certain fraction will decay. The theory may tell precisely what that fraction will be, but it cannot predict which particular nuclei will decay. The theory asserts that, at the beginning of the time interval, all the nuclei are in an identical state and that the decay is a completely random process. Even in classical physics, many processes appear random. For example, one says that, when a roulette wheel is spun, the ball will drop at random into one of the numbered compartments in the wheel. Based on this belief, the casino owner and the players give and accept identical odds against each number for each throw. However, the fact is that the winning number could be predicted if one noted the exact location of the wheel when the croupier released the ball, the initial speed of the wheel, and various other physical parameters. It is only ignorance of the initial conditions and the difficulty of doing the calculations that makes the outcome appear to be random. In quantum mechanics, on the other hand, the randomness is asserted to be absolutely fundamental. The theory says that, though one nucleus decayed and the other did not, they were previously in the identical state. They have rejected the notion that the nuclei were initially in the identical state. Instead, they postulated that there must be some other propertyâ€"presently unknown, but existing nonethelessâ€"that is different for the two nuclei. This type of unknown property is termed a hidden variable; if it existed, it would restore determinacy to physics. If the initial values of the hidden variables were known, it would be possible to predict which nuclei would decay. Such a theory would, of course, also have to account for the wealth of experimental data which conventional quantum mechanics explains from a few simple assumptions. Attempts have been made by de Broglie, David Bohm , and others to construct theories based on hidden variables, but the theories are very complicated and contrived. For example, the electron would definitely have to go through only one slit in the two-slit experiment. To explain that interference occurs only when the other slit is open, it is necessary to postulate a special force on the electron which exists only when that slit is open. Such artificial additions make hidden variable theories unattractive, and there is little support for them among physicists. The Copenhagen view of understanding the physical world stresses the importance of basing theory on what can be observed and measured experimentally. It therefore rejects the idea of hidden variables as quantities that cannot be measured. The Copenhagen view is that the indeterminacy observed in nature is fundamental and does not reflect an inadequacy in present scientific knowledge. Attempts have been made to link the existence of free will with the indeterminacy of quantum mechanics, but it is difficult to see how this feature of the theory makes free will more plausible. On the contrary, free will presumably implies rational thought and decision, whereas the essence of the indeterminism in quantum mechanics is that it is due to intrinsic randomness. Paradox of Einstein, Podolsky, and Rosen In Einstein and two other physicists in the United States , Boris Podolsky and Nathan Rosen , analyzed a thought experiment to measure position and momentum in a pair of interacting systems. Employing conventional quantum mechanics, they obtained some startling results, which led them to conclude that the theory does not give a complete description of physical reality. Their results, which are so peculiar as to seem paradoxical, are based on impeccable reasoning, but their conclusion that the theory is incomplete does not necessarily follow. Bohm simplified their experiment while retaining the central point of their reasoning; this discussion follows his account. The present discussion relates only to spin angular momentum, and the word spin is omitted from now on. It is possible to obtain a system consisting of a pair of protons in close proximity and with total angular momentum equal to zero. Suppose the two protons move in opposite directions until they are far apart. The total angular momentum of the system remains zero, and if the component of angular momentum along the same direction for each of the two particles is measured, the result is a pair of equal and opposite values. Therefore, after the quantity is measured for one of the protons, it can be predicted for the other proton; the second measurement is unnecessary. As previously noted, measuring a quantity changes the state of the system. Any direction, however, can be chosen for measuring the component of angular momentum. Whichever direction is selected, the state of proton 1 after measurement corresponds to a definite component of angular momentum about that direction. Furthermore, since proton 2 must have the opposite value for the same component, it follows that the measurement on proton 1 results in a definite state for proton 2 relative to the chosen direction, notwithstanding the fact that the two particles may be millions of kilometres apart and are not interacting with each other at the time. Einstein and his two collaborators thought that this conclusion was so obviously false that the quantum mechanical theory on which it was based must be incomplete. They concluded that the correct theory would contain some hidden variable feature that would restore the determinism of classical physics. A comparison of how quantum theory and classical theory describe angular momentum for particle pairs illustrates the essential difference between the two outlooks. In both theories, if a system of two particles has a total angular momentum of zero, then the angular momenta of the two particles are equal and opposite. If the components of angular momentum are measured along the same direction, the two values are numerically equal, one positive and the other negative. Thus, if one component is measured, the other can be predicted. The crucial difference between the two theories is that, in classical physics, the system under investigation is assumed to have possessed the quantity being measured beforehand. The measurement does not disturb the system; it merely reveals the preexisting state. It may be noted that, if a particle were actually to possess components of angular momentum prior to measurement, such quantities would constitute hidden variables. Does nature behave as quantum mechanics predicts? The interpretation of the results rests on an important theorem by the Irish-born physicist John Stewart Bell. Bell began by assuming the existence of some form of hidden variable with a value that would determine whether the measured angular momentum gives a plus or minus result. He further assumed localityâ€"namely, that measurement on one proton i. Both these assumptions agree with classical, commonsense ideas. That is to say, the observed results agree with those of quantum mechanics and cannot be accounted for by a hidden variable or deterministic theory based on the concept of locality. One is forced to conclude that the two protons are a correlated pair and that a measurement on one affects the state of both, no matter how far apart they are. This may strike one as highly peculiar, but such is the way nature appears to be. Experiment to determine the correlation in measured angular momentum values for a pair of protons with zero total angular momentum. The two protons are initially at the point 0 and move in opposite directions toward the two magnets. It may be noted that the effect on the state of proton 2 following a measurement on proton 1 is believed to be instantaneous; the effect happens before a light signal initiated by the measuring event at proton 1 reaches proton 2. Alain Aspect and his coworkers in Paris demonstrated this result in with an ingenious experiment in which the correlation between the two angular momenta was measured, within a very short time interval, by a high-frequency switching device. The interval was less than the time taken for a light signal to travel from one particle to the other at the two measurement positions. Thus, there is no way that the information concerning the direction of the measurement on the first proton could reach the second proton before the measurement was made on it. Measurement in quantum mechanics The way quantum mechanics treats the process of measurement has caused considerable debate. On the other hand, in the axiomatic approach to quantum mechanics described above, a measurement changes the wave function abruptly and discontinuously. This change, brought about by the process of measurement, is termed the collapse or reduction of the wave function. The difficulty is related to the fact that quantum mechanics applies to microscopic systems containing one or a few electrons, protons, or photons.

Chapter 8 : Tomâ€™s Top 10 interpretations of quantum mechanics | Science News

Interpretations of Quantum Mechanics Quantum mechanics is a physical theory developed in the s to account for the behavior of matter on the atomic scale. It has subsequently been developed into arguably the most empirically successful theory in the history of physics.

Instead, we have a wide array of differing interpretations of quantum mechanics, requiring additional ad hoc hypothetical conditions, inserted by hand, in order to make the formulation fit the particular interpretation favored. The absence of a general acceptance of any of these interpretations means, also, that none of these interpretations are actually free of conceptual problems. So what exactly is the underlying problem here? How is it that we cannot even interpret, consistently, the formulation of quantum mechanics that, together with the theory of relativity, forms the foundation of all modern physics? What we plan to explore, in this paper, is the possibility that the problem of interpretation may not actually reside in the basic mathematical formulation of quantum mechanics itself. The problem of interpreting quantum mechanics may, in fact, reside in having to fit the formulation into the prevailing philosophical view of reality that physicists subscribe to. In other words, we are looking at the possibility that the prevailing philosophical view of reality may, in fact, be incorrect, and that this may be the actual cause of the problems in interpreting quantum mechanics. Let us begin by looking at what the theory of relativityâ€”which forms the other half of the foundation of modern physicsâ€"tells us about the nature of our reality. This realization enables us to explain why the speed of light is constant in all inertial frames of reference. Since this constancy of the speed of light is a crucial starting postulate in the theory of relativity, it means that, by acknowledging our science as a science of our experience, we can even explain, to a large extent, why the theory of relativity exists. See Why Relativity Exists. On reflection, it is evident that our science must be a science of what we experience because the very data that is used for the formulation of our scientific theories comes from measurements made by conscious observers. Our scientific theories cannot be based on data that is free of the conscious observer, because unobserved data means no data! So our science must be a science of our experience. Now, if our science is a science of our experience and quantum mechanics reflects this experience by correctly describing what we find in our measurements, it follows logically that quantum mechanics provides important information about how we experience our reality. This is reinforced by the fact that the very formulation of quantum mechanics is centered on the observer and the results of measurements by the observer. The role of the observer is, in fact, so pivotal in quantum mechanics that the whole formulation would not even make sense without the observer! It is remarkable, then, that many physicists, instead of looking at what quantum mechanics tells us about our experience of reality, prefer to focus their efforts in trying to get rid of the observer. For more than a century now, physicists have repeatedly introduced new theoretical ideas to free quantum mechanics from the observer. As a result, there is now a whole array of interpretations of quantum mechanics, all aimed at negating the role of the observer, but with none of them fully succeeding in actually removing the observer. It is time to correct, at least to some extent, this unbalanced situation by now studying what quantum mechanics actually tells us about how we experience the universe, as well as what it tells us about the nature of our reality. For this reason, we will here adopt a direct experiential interpretation of quantum mechanics. We accept that the conscious observer necessarily plays a role in our science, and that quantum mechanics, in the first place, was formulated to fit the results of measurements made by the conscious observer. This, in fact, is not an assumption. It is actually the truth. We choose here not to battle against this truth but to simply accept it and see what we find. This is what we mean by a direct experiential interpretation of quantum mechanics. Imagine the scenario if we had, earlier in history, adopted the same approach concerning relativity, and accepted that the scientific definitions of time and space were, in the first place, designed to fit how we, the conscious observers, experience these entities. Again this would not have been an assumption. Now, if we had accepted this truth, and had learned that the physiological mechanisms of our body all run via electromagnetic transmission, we would, in fact, have been able to predict that the speed of light would always remain constant, relative to us, regardless of our state of motion. The direct experiential interpretation of the concepts of time and space would then have led to this falsifiable proposition. And we would have confirmed that this direct experiential interpretation did, in fact, correctly predict that the speed of light is constant relative to all frames of reference. In other words, theoretically, we could have predicted the results of the Michelson-Morley experiment even before it was performed if history had worked out differently! So now let us apply a similar direct experiential interpretation to quantum mechanics and see what we can learn from it. We shall do this without invoking artificially added ad hoc conditions to the basic rules of quantum mechanics. In other words, we will adopt an interpretation that accepts directly what the formulation of quantum mechanics is telling us about the reality that we experience. So let us begin now by outlining the formulation of quantum mechanics, in a way that the general reader can understand, and also demonstrate how pivotal the role of the observer is to this formulation. Fortunately, it is possible to present the formulation of quantum mechanics without the use of actual mathematics, and yet convey how and why the crucial philosophical problems arise from it. Keep in mind that even a full understanding of the mathematics behind quantum theory will not tell us why the mathematical formulation works in this way. As Richard Feynman says, nobody actually understands quantum physics. Physicists know how to compute the results of experiments using quantum mechanics, but we have no idea why the mathematics works. That may seem odd, but it is the truth. In a sense, physicists are like technicians who know how to operate a machine without actually knowing why the machine works. So readers need not feel that they do not understand something because they are not well versed in the mathematics. Take comfort that even those who are fully conversant with the mathematics also do not know why it works! Quantum mechanics basically involve a mathematical entity often in the form of a matrix known as the quantum wave function also called the quantum state. The quantum wave function actually presents us with the probability distribution of measurement results that can occur if and only if a measurement is made on the particle involved. Note, right from the onset, that quantum mechanics is about measurements by an observer and what the observer may find. Quantum mechanics does not provide us with direct rules governing the behaviour of particles. Incredibly, they only tell us about the particle indirectly, through rules governing the results of measurements made on the particle by an observer! That is why the very formulation of quantum mechanics would not even make sense without an observer. Let us simplify this idea of the quantum wave function with an analogy. Imagine the quantum wave function to be a special kind of cake of the birthday cake variety , which has within its structure, all the information we can possibly obtain about a particle if we make measurements on the particle. What is strange about this information found in the cake, though, is that it does not tell us anything definite about the particle. It only gives us a probability distribution of what we may find if we make an actual measurement on the particle. So how do we obtain this probability information about the particle from this cake? We have to follow a certain procedure, which in scientific language is as follows: If a measurement is made on a particleâ€"let us say, an electronâ€"an operator is applied to the quantum wave function. An operator is a mathematical procedure, and different operators correspond to different propertiesâ€"known as observablesâ€"of the particle that we want to measure. Now what happens to the quantum wave function when we apply a particular operator is this. The operator effectively informs us how to divide the quantum wave function into separate components known as eigenstates also known as eigenfunctions or eigenvectors. The set of eigenstates corresponding to a particular operator is known as its preferred basis. If we are looking at this in terms of our cake analogy, the operator is like a set of instructions on how to divide up our cake the quantum wave function. For measurement of different properties or observables of the particle our electron , we have different sets of instructions on how to divide up the cake. In other words, different operators divide the quantum wave function our cake into different types of eigenstates our parts of the cake. For example, one operator may tell us that the cake is to be divided into rectangular parts, while another operator may tell us that the cake is to be divided into triangular slices. Note that we are not actually cutting the cake yet, but are only marking out the divisions we only actually cut the cake when we make an actual measurement of the particle. The portions of the cake, so marked up for division, according to the instructions provided by the operator, are the eigenstates. The set of these parts of the cakeâ€"that the operator instructs us to mark outâ€"is known as the preferred basis of that particular operator. Each different operator therefore has a different preferred basis. The preferred basis for dividing up the quantum wave function is thus determined by the operator employed, which, in turn, is determined by the observable we choose to measure. Let us now add a new scientific term to our exposition of quantum mechanics: In scientific terminology, we say that different operators instruct us to consider the quantum wave function as a superposition of different sets of eigenstates. The word superposition essentially means a combination, where all the parts are basically added up or superimposed upon each other to form a whole. As long as we have not yet made an actual measurement, we can consider the quantum wave function to be a superposition of its eigenstates. Let us return to our cake analogy to illustrate the situation. Recall that we can imagine the quantum wave function to be like a birthday cake. When we apply an operator, it tells us how the cake is to be divided into parts, which are the eigenstates. In scientific terminology, we say that the quantum wave function our cake is formed by a superposition combination of all its eigenstates the parts of the cake. Note that the word superposition can only be used here if and only if we have not yet cut the cake. In other words, the parts of the cakeâ€”that we have marked outâ€”are actually still joined together. Once we actually cut the cake i. The important point is this: In other words, without an actual measurement being made on the electron, its quantum wave function is still intact, and we can still decide to change the operator we want to apply to it. As long as we have not made an actual measurement on the electron, we say that its quantum wave function our cake is a superposition combination of its eigenstates the parts of the cake. If we make an actual measurement, something unusual happens, and we can then no longer consider the quantum wave function as a superposition of its eigenstates. As we shall explain later, this is because something dramatic known as the collapse of the wave function happens to the quantum wave function once we actually make a measurement on the particle concerned. Let us now add something more the concept of eigenvalues to our exposition of the formulation of quantum mechanics, using scientific terminology: Recall that, for each different observable, when we apply its corresponding operator, the quantum wave function yields up a set of eigenstates. Now we learn that each eigenstate has a particular number or value attached to it, known as its corresponding eigenvalue. These eigenvalues represent the possible results of the measurement of that particular observable that the preferred basis of eigenstates correspond to. The complete set of eigenvalues of all the eigenstates represent the complete set of possible measurement results of the observable that we choose to measure. In other words, each eigenstate has an eigenvalue, and these eigenvalues are the different possible results or values that the observable can have if we were to actually measure that observable of the particle. Remember that each eigenvalue has its own eigenstate. So, in our example, when we apply the position operator, we find that the quantum wave function can be divided into three eigenstates. There are then three eigenvalues, one eigenvalue for each of the three eigenstates. When we apply our rules for dividing the cake the operator , we notice that the different parts of the cake the eigenstates each contain a label, which is a number or value the eigenvalues. Each part of the cake has a different label eigenvalue stuck to it. If the cake has been divided into three parts, there are three different labelsâ€”one for each part of the cake.

DOWNLOAD PDF INTERPRETING QUANTUM MECHANICS

Chapter 9 : [quant-ph/] The Interpretation of Quantum Mechanics: Many Worlds or Many Words?

What bothers some people about this interpretation is the random, abrupt change in the wave function, which violates the SchrÃ¶dinger equation, the very heart of quantum mechanics.

Jump to navigation Jump to search It has been suggested that this article or section be merged into Quantum mechanics. Discuss An interpretation of quantum mechanics is a set of statements which attempt to explain how quantum mechanics informs our understanding of nature. This science article is a stub. You can help Wikiquote by expanding it. Quotes[edit] Christian Imbert, to support my project and to act as my thesis advisor. He had advised me to go first to Geneva, to discuss my proposal with John Bell. While I explained my planned experiment, he listened silently. Eventually, I stopped talking, and the first question came: Remembering this first question reminds me both of his celebrated sense of humour and of the general atmosphere at that time about raising questions on the foundations of quantum mechanics. Quite frequently there was open hostility, and in the best case, irony: Bertlmann and Anton Zeilinger This particular question of locality is still open, in my opinion. I think we have not found a way of digesting this situation. We have the formulas of quantum mechanics, and they work extremely well; but I have not digested them. There certainly remains something to be said, some illumination to be found. John Stewart Bell , in interview, Omni, May , p. Voters either take sides and argue with each other endlessly, or stay home and accept politics as it is. Physicists either just accept quantum mechanics and do their calculations, or take sides in the never-ending debate over what quantum mechanics is actually saying about reality. There is no general consensus as to what its fundamental principles are, how it should be taught, or what it really "means. Griffith, Introduction to quantum mechanics 2nd ed. But when I revealed my impression of confusion and dissonance to one of the attendees, he reassured me that my perception was accurate. The problem, he noted, arose because, for the most part, the different interpretations of quantum mechanics cannot be empirically distinguished from one another; philosophers and physicists favor one interpretation over another for aesthetic and philosophicalâ€"that is, subjectiveâ€"reasons. The End of Science It is truly surprising how little difference all this makes. Most physicists use quantum mechanics every day in their working lives without needing to worry about the fundamental problem of its interpretation. Being sensible people with very little time to follow up all the ideas and data in their own specialties and not having to worry about this fundamental problem, they do not worry about it. A year or so ago, while Philip Candelas of the physics department at Texas and I were waiting for an elevator, our conversation turned to a young theorist who had been quite promising as a graduate student and who had then dropped out of sight. But I admit to some discomfort in working all my life in a theoretical framework that no one fully understands. And we really do need to understand quantum mechanics better in quantum cosmology, the application of quantum mechanics to the whole universe, where no outside observer is even imaginable. The universe is much too large now for quantum mechanics to make much difference, but according to the big-bang theory there was a time in the past when the particles were so close together that quantum effects must have been important. No one today knows even the rules for applying quantum mechanics in this context. Quantum Mechanics and Its Discontents My own conclusion is that today there is no interpretation of quantum mechanics that does not have serious flaws. This view is not universally shared. Indeed, many physicists are satisfied with their own interpretation of quantum mechanics. But different physicists are satisfied with different interpretations. In my view, we ought to take seriously the possibility of finding some more satisfactory other theory, to which quantum mechanics is only a good approximation. Steven Weinberg , Lectures on Quantum Mechanics 2nd ed. General Principles of Quantum Mechanics I had the feeling that the stuff was beautiful. I learned it from Weyl, and Weyl had the art of putting things in a lovely perspective. More so than anybody else I have ever read. That book was just a treat. I only got in two or three sentences this morning.