DOWNLOAD PDF INCOMPATIBILITY WITH QUANTUM MECHANICS

Chapter 1 : Quantum Incompatibility

Physicist: Quantum Mechanics (QM) and relativity are both % accurate, so far as we have been able to measure (and our measurements are really, really good). The incompatibility shows up when both QM effects and relativistic effects are large enough to be detected and then disagree. This.

Recently, I started thinking about this a bit more. So I conducted a survey asking my scientist friends and also friends that were at some point in the past involved in science to answer two questions: How do you imagine or visualize wave-particle duality? Do you imagine a particle, a wave, or something else, or nothing? I discuss the answers that were given below. Sometimes they say that space-time is 4-dimensional, and sometimes they say that the universe has 11 dimensions or some other arbitrary number. Some even talk about infinite-dimensional spaces I know some that will engage in lengthy discussions about the intricacies of infinite-dimensional spaces, yet are quite lost when the discussion turns into finite dimensions. The answer is simple: One can easily think of the fourth dimension as time, or color. So, what do we do with higher dimensions? In other words we just need to look at the underlying mathematical formalism and keep in mind the rules that are applied. A nice analogy to understanding the way we imagine things was given to me by Andrej Gendiar. They project the problem either into 3D or 2D space, which our brains are accustomed to. In the same way you can assess the properties of a hanging object from its shadows on the wall, one assesses what happens in higher dimensions from what happens in the lower-dimensional case. Wave-particle duality While the first question was just to confirm my suspicions, the second question was more interesting to me. Before we consider the given answers, what do I mean by wave-particle duality? One is that the particle will hit the wall at a point-like location like a particle, right? There is certainly more to be said on the topic see e. Wikipedia but this blog is not about the effect. It turned out that all these visualizations were, however, only a crutch. That is why at one point or another our inherent intuition fails. The things we talk about that cannot be imagined are always based on a solid mathematical background that we respect. There is, however one point worth mentioning: No animals or scientists were harmed during the experiment. Many thanks to Tom Bullock for having the patience to go through the text and for his corrections.

Chapter 2 : The Final Contradiction

Historically, the problem was a technical one. After theorists found methods for applying quantum theory to particles (the SchrÃ¶dinger equation and the Dirac equation) they sought a method for applying quantum ideas to fields (such as the electric.

Received Sep 15; Accepted Aug To view a copy of this license, visit http: Abstract The existence of observables that are incompatible or not jointly measurable is a characteristic feature of quantum mechanics, which lies at the root of a number of nonclassical phenomena, such as uncertainty relations, waveâ€"particle dual behavior, Bell-inequality violation, and contextuality. However, no intuitive criterion is available for determining the compatibility of even two generalized observables, despite the overarching importance of this problem and intensive efforts of many researchers. Here we introduce an information theoretic paradigm together with an intuitive geometric picture for decoding incompatible observables, starting from two simple ideas: Every observable can only provide limited information and information is monotonic under data processing. By virtue of quantum estimation theory, we introduce a family of universal criteria for detecting incompatible observables and a natural measure of incompatibility, which are applicable to arbitrary number of arbitrary observables. Based on this framework, we derive a family of universal measurement uncertainty relations, provide a simple information theoretic explanation of quantitative waveâ€"particle duality, and offer new perspectives for understanding Bell nonlocality, contextuality, and quantum precision limit. Observables that are incompatible or not jointly measurable play a fundamental role in quantum mechanics and quantum information science. Profound consequences of incompatible observables were realized soon after the inception of quantum theory by Heisenberg in the seminal paper 1 , from which originated the idea of uncertainty relations 2 , 3. Around the same time, Bohr conceived the idea of the complementarity principle 4. A vivid manifestation is the famous example of waveâ€"particle duality 4 , 5 , 6 , 7 , 8 , 9. In addition, incompatible observables are intimately connected to Bell nonlocality 10 , 11 , 12 , Einsteinâ€"Podolskyâ€"Rosen EPR steering 13 , 14 , 15 , contextuality 16 , 17 , 18 , 19 , superdense coding 20 , etc. The implications of incompatibility have never been fully explored, as reflected in a recent heated debate on as well as resurgence of interest in measurement uncertainty and error-disturbance relations 2 , 21 , 22 , Most existing literature on incompatible observables focus on two sharp observables those represented by self-adjoint operators , partly due to the lack of a suitable tool for dealing with more observables or generalized observables those described by probability operator measurements, also known as positive operator valued measures. With the advance of quantum information science and technologies, it is becoming increasingly important to consider more general situations. Detection and characterization of incompatible observables is thus of paramount importance. There exist a number of different notions characterizing the compatibility relations among quantum observables; prominent examples include commutativity, nondisturbance, joint measurability, and coexistence 24 , For sharp observables, all four notions are equivalent For generalized observables, however, all of them are inequivalent: Among the four notions of compatibility mentioned above, joint measurability is distinguished by its close relation to Bell nonlocality 10 , 11 , 12 and EPR steering 13 , 14 , In particular, a set of observables is not joint measurable if and only if it can be used to reveal EPR steering 14 , In the rest of this paper, we shall focus on the compatibility relations captured by the notion of joint measurability. Although the compatibility of a set of observables can be determined by semidefinite programming 27 , the computational complexity increases exponentially with the number of observables. In addition, existing algorithms provide little intuition as to why a set of observables is compatible or not. Actually, no intuitive criteria is known for determining the compatibility of even two generalized observables, except for a few special cases, such as two binary observables in the case of a qubit 9 , 28 , 29 , 30 , What is worse, most known criteria are derived with either brute force or ad hoc mathematical tricks, which offer little insight even if the conclusions are found. In this work we aim to change this situation. In addition to the detection of incompatibility, quantification of incompatibility is also of paramount importance. Incompatibility measures are closely related to quantitative waveâ€"particle duality relations 5 , 6

, 7 , 8 , 9 and measurement uncertainty relations 2 , In this context, it is instructive to distinguish two different uncertainty relations concerning state preparations and measurements, respectively, as clarified in ref. The traditional uncertainty relation, encoded in the Robertson inequality 33 , characterizes preparation uncertainty. Although this is well known as the Heisenberg uncertainty relation, it is different from the measurement uncertainty relation Heisenberg had in mind 1 , Also, most other uncertainty relations known in the literature belong to this type, including many entropic uncertainty relations 3. By contrast, few works have studied measurement uncertainty relations for a long time; notable exceptions include refs 34 , Recently, increasing attention has been directed to measurement uncertainty relations and incompatibility measures 2 , 21 , 22 , 23 , However, most works are tailored to deal with restricted scenarios, such as von Neumann observables or two generalized observables. More powerful tools are needed to deal with general settings. In this work we propose a new paradigm for detecting and characterizing incompatible observables. Our framework is based on simple information theoretical ideas and quantum estimation theory 37 , The Fisher information underpinning our study turns out to be more effective than Shannon information in capturing the compatibility relations among different observables. In particular, we introduce a family of universal criteria for detecting incompatible observables and a natural measure of incompatibility, which are applicable to arbitrary number of arbitrary observables. Based on this framework, we derive a family of universal measurement uncertainty relations, which substantially improve over known uncertainty relations in terms of the scope of applicability. We also provide a simple information theoretic explanation of quantitative waveâ€”particle duality and derive complementary relations for more than two complementary observables. In addition, our work offers new perspectives for understanding Bell nonlocality, EPR steering, contextuality, and quantum precision limit. Results Simple ideas Our approach for detecting and characterizing incompatible observables is based on two simple information theoretic ideas: The joint observable of a set of observables is at least as informative as each marginal observable with respect to any reasonable information measure. A set of observables cannot be compatible if any hypothetical joint measurement would provide too much information. These ideas are general enough for dealing with arbitrary number of arbitrary observables. Furthermore, they are applicable not only to the quantum theory, but also to generalized probability theories 39 , For concreteness, however, we shall focus on the quantum theory. Although information measures are not a priori unique, we find the Fisher information 41 is a perfect choice for our purpose. Compared with Shannon information commonly employed in relevant studies, Fisher information is usually quantified by a matrix instead of a scalar and is more suitable in characterizing different information provided by different observables. In particular, Fisher information is more effective in capturing the information tradeoff among incompatible observables. In addition, many tools in quantum estimation theory 37 , 38 can be applied to derive incompatibility criteria and measures in a systematic way instead of relying on ad hoc mathematical tricks, as is the case in most existing studies. Consequently, the incompatibility criteria and measures we derive are more intuitive and have a wider applicability. If there exists a unique maximal Fisher information matrix , say, provided by the most informative measurement, as in the case of classical probability theory, then is represented by the intersection of two opposite cones characterized by the equation. Except in the one-parameter setting, however, this is generally not the case for the quantum theory and also generalized probability theories. Additional constraints on the complementarity chamber reflect subtle information tradeoff among incompatible observables, which is a direct manifestation of the complementarity principle. Alternatively, these constraints may be understood as epistemic restrictions imposed by the underlying theory. Characterize information complementarity with quantum estimation theory To unleash the potential of the ideas presented in the previous section, it is essential to understand the structure of the complementarity chamber or, equivalently, the constraints on the set of realizable Fisher information matrices. In the case of quantum theory, a powerful tool for this purpose is quantum estimation theory developed over the past half century 37 , 38 , 42 , 43 see supplementary information. A generalized observable or measurement is determined by a set of positive operators that sum up to the identity. Accordingly, the Fisher information matrix takes on the form As mentioned previously, the inverse Fisher information matrix sets a lower bound for the MSE matrix of any unbiased estimator. However, the bound is applicable only to the specific measurement. To understand the structure of the complementarity chamber, it is desirable to find constraints on the Fisher information matrix that is measurement independent. In the multiparameter setting, however, the bound generally cannot be saturated because the SLDs associated with different parameters are incompatible. To determine the complementarity chamber in the multiparameter setting, it is necessary to consider additional constraints on the Fisher information matrix that take into account the information tradeoff among incompatible observables. Such information tradeoff is best characterized by the Gillâ€"Massar GM inequality 42 which is applicable to any measurement on a d-level system. The GM inequality is useful not only to studying the complementarity chamber and compatibility problem but also to studying multiparameter quantum estimation problems 42 , Information complementarity illustrated As an illustration, here we determine the complementarity chamber of the qubit in comparison with that of the probability simplex. In the case of a qubit, the GM inequality turns out to be both necessary and sufficient for characterizing the complementarity chamber. Moreover, any Fisher information matrix saturating the GM inequality can be realized by three mutually unbiased measurements 42 , 43 see supplementary information. This observation is crucial to attaining the tomographic precision limit in experiments Fisher information matrices of von Neumann measurements determined by antipodal points on the Bloch sphere correspond to normalized pure states, while those of noisy von Neumann measurements correspond to subnormalized pure states. When , the complementarity chamber is a distorted cone. The metric-adjusted complementarity chamber , nevertheless, has the same size and shape irrespective of the parameter point. To visualize the complementarity chamber, it is instructive to consider the real qubit. With respect to the quantum Fisher information metric 45 , the state space is a hemisphere. Each metric-adjusted complementarity chamber is isomorphic to the state space for the two-dimensional real Hilbert space, and is represented by a circular cone, as illustrated in the lower plot of Fig. This is in sharp contrast with the complementarity chamber on the probability simplex with three components , which is represented by the union of two opposite cones; see the upper plot of Fig. The missing cone of hypothetical Fisher information matrices for the real qubit is excluded by the GM inequality. Figure 1 is a vivid manifestation of the viewpoint that regards quantum theory as a classical probability theory with epistemic restrictions.

Chapter 3 : Relativity v quantum mechanics â€“ the battle for the universe | News | The Guardian

Although it would be more precise to say that gravity is the manifestation of the effect of curved space-time on moving bodies, and it is mass that curves the space-time, so prof. Rennie is correct about this, there are differences of opinion, at least, about the other aspects.

Introduction Dutch artist M. Some of his work, for example Ascending and Descending, relies on optical illusion to depict what is actually an impossible situation. Other works are paradoxical in the broad sense, but not impossible: Relativity depicts a coherent arrangement of objects, albeit an arrangement in which the force of gravity operates in an unfamiliar fashion. See the Other Internet Resources section below for images. Quantum gravity itself may be like this: Or it may be more like Ascending and Descending, an impossible construction which looks sensible in its local details but does not fit together into a coherent whole when using presently existing building materials. If the latter is true, then the construction of a quantum theory of gravity may demand entirely unfamiliar elements. Whatever the final outcome, the situation at present is one of flux, with a great many competing approaches vying for the prize. However, it is also important to note that the prize is not always the same: Other approaches are more modest, and seek only to bring general relativity in line with quantum theory, without necessarily invoking the other interactions. Hence, the problem of quantum gravity can mean very different things to different researchers and what constitutes a possible solution to one group might not qualify as such to another. Given that quantum gravity does not yet exist as a working physical theory, one might legitimately question whether philosophers have any business being involved at this stage. In such cases, one typically proceeds by assuming the physical soundness of the theory or theoretical framework and drawing out the ontological and perhaps epistemological consequences of the theory, trying to understand what it is that the theory is telling us about the nature of space, time, matter, causation, and so on. Theories of quantum gravity, on the other hand, are bedeviled by a host of technical and conceptual problems, questions, and issues that make them largely unsuited to this kind of interpretive approach. However, philosophers who have a taste for a broader and more open-ended form of inquiry will find much to think about, and it is entirely possible that future philosophers of physics will be faced with problems of a very different flavour as a result of the peculiar nature of quantum gravity. This raises an important point: In doing so, they manage to encompass traditional, Newtonian gravitational phenomena such as the mutual attraction of two or more massive objects, while also predicting new phenomena such as the bending and red-shifting of light by these objects which have been observed and the existence of gravitational radiation until very recently, with the direct detection of gravitational waves by LIGO, this was, of course, only indirectly observed via the decrease in the period of binary pulsars-see the Physics Nobel Prize presentation speech by Carl Nordling. These quantities are represented by tensor fields, sets of real numbers associated with each spacetime point. For example, the stress, energy, and momentum Tab x,t of the electromagnetic field at some point x,t , are functions of the three components Ei, Ej, Ek, Bi, Bj, Bk of the electric and magnetic fields E and B at that point. The metric gab x,t is a set of numbers associated with each point which gives the distance to neighboring points. A model of the world according to general relativity consists of a spacetime manifold with a metric, the curvature of which is constrained by the stress-energy-momentum of the matter distribution. All physical quantities â€” the value of the x-component of the electric field at some point, the scalar curvature of spacetime at some point, and so on â€” have definite values, given by real as opposed to complex or imaginary numbers. Thus general relativity is a classical theory in the sense given above. The problem is that our fundamental theories of matter and energy, the theories describing the interactions of various particles via the electromagnetic force and the strong and weak nuclear forces, are all quantum theories. In quantum theories , these physical quantities do not in general have definite values. For example, in quantum mechanics, the position of an electron may be specified with arbitrarily high accuracy only at the cost of a loss of specificity in the description of its momentum, hence its velocity. At the same time, in the quantum theory of the electromagnetic field known as quantum electrodynamics QED , the electric and magnetic fields associated with the electron suffer an associated uncertainty. In general, physical quantities are described by a quantum state which gives a probability distribution over many different values, and increased specificity narrowing of the distribution of one property e. Likewise, if one focusses in on the spatial geometry, it will not have a definite trajectory. On the surface, the incompatibility between general relativity and quantum theory might seem rather trivial. Why not just follow the model of QED and quantize the gravitational field, similar to the way in which the electromagnetic field was quantized? This is more or less the path that was taken, but it encounters extraordinary difficulties. However, these technical problems are closely related to a set of daunting conceptual difficulties, of interest to both physicists and philosophers. The conceptual difficulties basically follow from the nature of the gravitational interaction, in particular the equivalence of gravitational and inertial mass, which allows one to represent gravity as a property of spacetime itself, rather than as a field propagating in a passive spacetime background. When one attempts to quantize gravity, one is subjecting some of the properties of spacetime to quantum fluctuations. For example, in canonical quantizations of gravity one isolates and then quantizes geometrical quantities roughly the intrinsic and extrinsic curvature of three dimensional space functioning as the position and momentum variables. Given the uncertainty principle and the probabilistic nature of quantum theory, one has a picture involving fluctuations of the geometry of space, much as the electric and magnetic fields fluctuate in QED. But ordinary quantum theory presupposes a well-defined classical background against which to define these fluctuations Weinstein, a, b , and so one runs into trouble not only in giving a mathematical characterization of the quantization procedure how to take into account these fluctuations in the effective spacetime structure? For example, a fluctuating metric would seem to imply a fluctuating causal structure and spatiotemporal ordering of events, in which case, how is one to define equal-time commutation relations in the quantum theory? See the section on the Lagrangian formulation in the entry on quantum field theory. Cao believes that the conceptual nature of the problem demands a conceptual resolution. This approach asks for an analysis of the ontological pictures of the two ingredient theories of quantum gravity, so that their consistency the consistency of the resulting synthesis can be properly assessed. Ontology for Cao refers to the primary, autonomous structures from which all other properties and relations in a theory are constructed. A fairly simple inspection of the respective ontological constraints imposed by general relativity and quantum field theory reveals serious tension: On the other hand, as we have seen, quantum field theory involves quantum fluctuations in the vicinity of a point, while general relativity involves the use of a smooth point neighbourhood. Either way, in order to bring the two ontological bases together, some piece of either edifice must be demolished. Cao proposes that the tension can best be resolved by focussing firmly on those sine qua non principles of the respective theories. Likewise, he argues that quantum field theory requires a fixed background in order to localize quantum fields and set up causal structure. But he notes that a relational account of localization could perform such a function, with fields localized relative to each other. In so doing, one could envisage a diffeomorphism covariant quantum field theory i. The resulting synthesized entity a violently fluctuating, universally coupled quantum gravitational field would then be what a quantum theory of gravity ought to describe. While such an approach sounds sensible enough on the surface, to actually put it into practice in the constructive stages of theory-building rather than a retrospective analysis of a completed theory is not going to be easyâ€"though it has to be said, the method Cao describes bears close resemblance to the way loop quantum gravity has developed. The causaloid approach is intended to provide a framework for quantum gravity theories, where idea is to develop a general formalism that respects the key features of both general relativity, which he takes to be the dynamical non-probabilistic causal structure, and quantum theory, which he takes to be the probabilistic nondynamical dynamics. The causaloid of some theory is an entity that encodes all that can be calculated in the theory. However, it is perfectly possible that both of the input theories break down at higher energies. Not only that, the technical difficulties of setting up the kind of physically realistic diffeomorphism-invariant quantum field theory he suggests have so far proven to be an insurmountable challenge. Of course, they must be relational, but this still leaves the problem very much open. The idea of making progress by isolating appropriate principles of quantum gravity forms the basis of a special issue: Crowther and Rickles, eds, We will look in more detail at how various conceptual and methodological problems arise in two different research programs below. But first, we introduce some key features of the leading research programs. Theoretical Frameworks All approaches to the problem of quantum gravity agree that something must be said about the relationship between gravitation and quantized matter. These various approaches can be catalogued in various ways, depending on the relative weight assigned to general relativity and quantum field theory. Some approaches view general relativity as in need of correction and quantum field theory as generally applicable, while others view quantum field theory as problematic and general relativity as having a more universal status. Still others view the theories in a more even-handed manner, perhaps with both simply amounting to distinct limits of a deeper theory. It has often been suggested, since the earliest days of quantum gravity research, that bringing quantum field theory and general relativity together might serve to cure their respective singularity problems the former resulting from bad high frequency behaviour of fields; the latter resulting from certain kinds of gravitational collapse. This hope does seem to have been borne out in many of the current approaches. Roger Penrose has even argued that the joint consideration of gravitation and quantum theory could resolve the infamous quantum measurement problem see Penrose ; see also the section on the measurement problem in the entry on philosophical issues in quantum theory. There are difficulties in distinguishing the gravitationally induced collapse that Penrose proposes from the effective collapse induced by quantum theory itself, thanks to decoherenceâ€"Joy Christian has suggested that by observing oscillations in the flavor ratios of neutrinos originating at cosmological distances one could eliminate the confounding effects of environmental decoherence. By far the two most popular approaches are string theory and loop quantum gravity. The former is an example of an approach to quantum gravity in which the gravitational field is not quantized; rather, a distinct theory is quantized which happens to coincide with general relativity at low energies. The latter is an approach involving constrained canonical quantization, albeit of a version of general relativity based on a different choice of variables than the usual geometrodynamical, metric-based variables. We cover the basic details of each of these in the following subsections. However, it turned out that the theory is not perturbatively renormalizable, meaning that there are ineliminable infinities. The original and still prominent idea behind string theory was to replace the point particles of ordinary quantum field theory particles like photons, electrons, etc with one-dimensional extended objects called strings. See Weingard, and Witten, for overviews of the conceptual framework. String theories containing fermions as well as bosons must be formulated in nine space dimensions and one time dimension. Strings can be open or closed, and have a characteristic tension and hence vibrational spectrum. The various modes of vibration correspond to various particles, one of which is the graviton the hypothetical massless, spin-2 particle responsible for mediating gravitational interactions. The resulting theories have the advantage of being perturbatively renormalizable. This means that perturbative calculations are at least mathematically tractable. Since perturbation theory is an almost indispensable tool for physicists, this is deemed a good thing. The rationale, according to one kind of duality S-duality , is that one theory at strong coupling high energy description is physically equivalent in terms of physical symmetries, correlation functions and all observable content to another theory at weak coupling where a lower energy means a more tractable description , and that if all the theories are related to one another by dualities such as this, then they must all be aspects of some more fundamental theory. Though attempts have been made, there has been no successful formulation of this theory: The link comes about because in a dual pair of theories one has a observable equivalence combined with what appears to be radical physical and mathematical differences. These differences can be as extreme as describing spacetimes of apparently different topological structures, including different numbers of dimensions. This has led some physicists to speak of spacetime emerging, depending on such things as the coupling strength governing physical interactions. Since there is an equivalence between these descriptions, it makes sense to say that neither is fundamental, and so elements of the spacetimes they apparently describe are also not fundamental; thus implying that the spacetime we observe at low-energies is an emergent phenomenon â€" Vistarini is a recent discussion of spacetime emergence in string theory. One way to view such dual pairs is in terms of the two theories the gauge theory and a gravitational theory being distinct classical limits of a more all-encompassing quantum theory. In this case, the classical emergent structures also include the specific gauge symmetries and degrees of freedom of the limiting theories. A problem remains of making sense of the more fundamental theory and the associated physical structure it describes from which these spacetimes and gauge symmetries emerge. However, if we view the theories as notational variants, then our sense of theory-individuation is seemingly compromised, since the dual pairs involve different dynamics and degrees of freedom. See Joseph Polchinski , for a thorough account of the various kinds of dualities along with some of their interpretive quirks; Rickles provides a philosophical examination of string dualities. However, spacetime itself is split apart into a stack of three dimensional slices a foliation on which is defined a spatial geometry. In a canonical description, one chooses a particular set of configuration variables xi and canonically conjugate momentum variables pi which describe the state of a system at some time, and can be encoded in a phase space. Then, one obtains the time-evolution of these variables from the Hamiltonian H xi,pi , which provides the physically possible motions in the phase space a a family of curves. The Hamiltonian operator, acting on quantum states, would then generate the dynamical evolution. When one attempts to write general relativity down in this way, one has to contend with the existence of constraints on the canonical variables that are inherited from the diffeomorphism invariance of the spacetime formulation of the theory.

Chapter 4 : Incompatibility Between Relativity and Quantum Mechanics - Physics Stack Exchange

Quantum mechanics is incompatible with general relativity because in quantum field theory, forces act locally through the exchange of well-defined quanta. Return to the Special & General Relativity Questions and Answers page.

Introduction The uncertainty principle is certainly one of the most famous aspects of quantum mechanics. It has often been regarded as the most distinctive feature in which quantum mechanics differs from classical theories of the physical world. Roughly speaking, the uncertainty principle for position and momentum states that one cannot assign exact simultaneous values to the position and momentum of a physical system. But what is the exact meaning of this principle, and indeed, is it really a principle of quantum mechanics? In his original work, Heisenberg only speaks of uncertainty relations. And, in particular, what does it mean to say that a quantity is determined only up to some uncertainty? These are the main questions we will explore in the following, focusing on the views of Heisenberg and Bohr. It may refer to a lack of knowledge of a quantity by an observer, or to the experimental inaccuracy with which a quantity is measured, or to some ambiguity in the definition of a quantity, or to a statistical spread in an ensemble of similarly prepared systems. Also, several different names are used for such uncertainties: As we shall see, even Heisenberg and Bohr did not decide on a single terminology for quantum mechanical uncertainties. A partial translation of this title is: Here, the term anschaulich is particularly notable. Apparently, it is one of those German words that defy an unambiguous translation into other languages. But, as in most languages, words that make reference to vision are not always intended literally. Seeing is widely used as a metaphor for understanding, especially for immediate understanding. This question has already been considered by a number of commentators Jammer ; Miller ; de Regt ; Beller For the answer, it turns out, we must go back a little in time. In Heisenberg had developed the first coherent mathematical formalism for quantum theory Heisenberg His leading idea was that only those quantities that are in principle observable should play a role in the theory, and that all attempts to form a picture of what goes on inside the atom should be avoided. In atomic physics the observational data were obtained from spectroscopy and associated with atomic transitions. Max Born, later that year, realized that the transition quantities obeyed the rules of matrix calculus, a branch of mathematics that was not so well-known then as it is now. In a famous series of papers Heisenberg, Born and Jordan developed this idea into the matrix mechanics version of quantum theory. Formally, matrix mechanics remains close to classical mechanics. The central idea is that all physical quantities must be represented by infinite self-adjoint matrices later identified with operators on a Hilbert space. The new theory scored spectacular empirical success by encompassing nearly all spectroscopic data known at the time, especially after the concept of the electron spin was included in the theoretical framework. The discrete frequencies in the atomic spectra were not due to discontinuous transitions quantum jumps as in matrix mechanics, but to a resonance phenomenon. He considered this condition of Anschaulichkeit to be an essential requirement on any acceptable physical theory. Many other leading physicists were attracted to wave mechanics for the same reason. Understandably, Heisenberg was unhappy about this development. Again, this last German term is translated differently by various commentators: Nevertheless, in published writings, Heisenberg voiced a more balanced opinion. In a paper in Die Naturwissenschaften he summarized the peculiar situation that the simultaneous development of two competing theories had brought about. The purpose of his paper was to provide exactly this lacking feature. He started by redefining the notion of Anschaulichkeit. We believe we have gained anschaulich understanding of a physical theory, if in all simple cases, we can grasp the experimental consequences qualitatively and see that the theory does not lead to any contradictions. To do this, he adopted an operational assumption: In general, there is no lack of such experiments, even in the domain of atomic physics. However, experiments are never completely accurate. We should be prepared to accept, therefore, that in general the meaning of these quantities is also determined only up to some characteristic inaccuracy. As an example, he considered the measurement of the position of an electron by a microscope. The accuracy of such a measurement is limited by the wave length of the light illuminating the electron. Thus, it is possible, in principle, to make such a position measurement as accurate as one wishes, by using light of a very short wave length, e. In such a collision, the electron suffers a recoil which disturbs its momentum. Moreover, the shorter the wave length, the larger is this change in momentum. Thus, at the moment when the position of the particle is accurately known, Heisenberg argued, its momentum cannot be accurately known: At the instant of time when the position is determined, that is, at the instant when the photon is scattered by the electron, the electron undergoes a discontinuous change in momentum. This change is the greater the smaller the wavelength of the light employed, i. At the instant at which the position of the electron is known, its momentum therefore can be known only up to magnitudes which correspond to that discontinuous change; thus, the more precisely the position is determined, the less precisely the momentum is known, and conversely. In its present form it is an epistemological principle, since it limits what we can know about the electron. In particular, the status of the time variable in his several illustrations of relation 3 is not at all clear Hilgevoord ; see also Section 2. Heisenberg summarized his findings in a general conclusion: Note that in this formulation the emphasis has slightly shifted: Among other things, Bohr pointed out that in the microscope experiment it is not the change of the momentum of the electron that is important, but rather the circumstance that this change cannot be precisely determined in the same experiment. A solution to this problem can again be found in the Chicago lectures Heisenberg Here, he assumes that initially the momentum of the electron is precisely known, e. All three measurements can be performed with arbitrary precision. If we assume further that the initial momentum has not changed until the position measurement, we can speak of a definite momentum until the time of the position measurement. Moreover we can give operational meaning to the idea that the momentum is changed during the position measurement: In fact, one can also show that this change is discontinuous, by varying the time between the three measurements. One might, perhaps, claim that the value at the very instant of the position measurement is not yet defined, but we could simply settle this by a convention, e. A solution to this problem can again be found in the Chicago Lectures. Heisenberg admits that position and momentum can be known exactly. If the velocity of the electron is at first known, and the position then exactly measured, the position of the electron for times previous to the position measurement may be calculated. Apparently, when Heisenberg refers to the uncertainty or imprecision of a quantity, he means that the value of this quantity cannot be given beforehand. In the sequence of measurements we have considered above, the uncertainty in the momentum after the measurement of position has occurred, refers to the idea that the value of the momentum is not fixed just before the final momentum measurement takes place. Clearly, then, Heisenberg is concerned with unpredictability: It is, however always possible to measure, and hence define, the size of this change in a subsequent measurement of the final momentum with arbitrary precision. Although Heisenberg admits that we can consistently attribute values of momentum and position to an electron in the past, he sees little merit in such talk. He points out that these values can never be used as initial conditions in a prediction about the future behavior of the electron, or subjected to experimental verification. Whether or not we grant them physical reality is, as he puts it, a matter of personal taste. It is an ontological principle, for it states what is physically real. This then leads to the following picture. First we measure the momentum of the electron very accurately. At this instant, the position of the particle becomes well-defined and, again, one can regard this as a physically real attribute of the particle. The meaning and validity of this claim can be verified by a subsequent momentum measurement. The question is then what status we shall assign to the momentum of the electron just before its final measurement. According to Heisenberg it is not. Before the final measurement, the best we can attribute to the electron is some unsharp, or fuzzy momentum. These terms are meant here in an ontological sense, characterizing a real attribute of the electron. The interpretation of these relations has often been debated. Or else, are they restrictions of an ontological nature, i. The difference between these interpretations is partly reflected in the various names by which the relations are known, e. The debate between these views has been addressed by many authors, but it has never been settled completely. Let it suffice here to make only two general observations. However, ontological questions seemed to be of somewhat less interest to him. For example, there is a passage Heisenberg He emphatically dismisses this conception as an unfruitful and meaningless speculation, because, as he says, the aim of physics is only to describe observable data. Similarly, in the Chicago Lectures, he warns against the fact that the human language permits the utterance of statements which have no empirical content, but nevertheless produce a picture in our imagination. The second observation is that although for Heisenberg experimental, informational, epistemological and ontological formulations of his relations were, so to say, just different sides of the same coin, this is not so for those who do not share his operational principles or his view on the task of physics. Alternative points of view, in which e. The statement, often found in the literature of the thirties, that Heisenberg had proved the impossibility of associating a definite position and momentum to a particle is certainly wrong. And because no agreement has been reached on this latter issue, one cannot expect agreement on the meaning of the uncertainty relations either. In the English literature the name uncertainty principle became most common. But this can well be read as his yielding to common practice rather than his own preference. But does the relation 2 qualify as a principle of quantum mechanics? Several authors, foremost Karl Popper , have contested this view. Popper argued that the uncertainty relations cannot be granted the status of a principle on the grounds that they are derivable from the theory, whereas one cannot obtain the theory from the uncertainty relations. There are many statements in physical theories which are called principles even though they are in fact derivable from other statements in the theory in question. Einstein proposed this famous classification in Einstein

Chapter 5 : Quantum gravity - Wikipedia

Incompatibility of observables in quantum mechanics A crucial difference between classical quantities and quantum mechanical observables is that the latter may not be simultaneously measurable, a property referred to as complementarity.

The Final Contradiction The results described above constitute quite an achievement for one century, but it leaves us with one fundamental contradiction that still needs to be resolved. General relativity and quantum field theory are incompatible. Many theorical physicists are convinced that superstring theory will provide the answer. After presenting some more background, I will describe the recent developments and their implications. There are various problems that arise when one attempts to combine general relativity and quantum field theory. The field theorist would point to the breakdown of the usual procedure for eliminating infinities from calculations of physical quantities. This procedure is called "renormalization", and when it fails the theory is said to be "non-renormalizable. By replacing point-like particles with one-dimensional extended strings, as the fundamental objects, superstring theory overcomes the problem of non-renormalizability. An expert in general relativity might point to a different set of problems such as the issue of how to understand the causal structure of space-time when the geometry has quantum-mechanical excitations. There are also a host of problems associated to black holes such as the fundamental origin of their thermodynamic properties and their apparent incompatibility with quantum mechanics. The latter, if true, would mean that a modification in the basic structure of quantum mechanics is required. In fact, superstring theory does not modify quantum mechanics; rather, it modifies general relativity. Most string theorists expect that the theory will provide satisfying resolutions of these problems without any revision in the basic structure of quantum mechanics. Indeed, there are indications that someday quantum mechanics will be viewed as an implication or at least a necessary ingredient of superstring theory. When a new theoretical edifice is proposed, it is very desirable to identify distinctive testable experimental predictions. In the case of superstring theory there have been no detailed computations of the properties of elementary particles or the structure of the universe that are convincing, though many valiant attempts have been made. In my opinion, success in such enterprises requires a better understanding of the theory than has been achieved as yet. It is very difficult to assess whether this level of understanding is just around the corner or whether it will take many decades and several more revolutions. In the absence of this kind of confirmation, we can point to three qualitative "predictions" of superstring theory. The first is the existence of gravitation, approximated at low energies by general relativity. No other quantum theory can claim to have this property and I suspect that no other ever will. The second is the fact that superstring solutions generally include Yang--Mills gauge theories like those that make up the "standard model" of elementary particles. The third general prediction is the existence of supersymmetry at low energies the electroweak scale. Since supersymmetry is the major qualitiative prediction of superstring theory not already known to be true before the prediction, let us look at it a little more closely. One could imagine that in some other civilization, the sequence of discoveries is different.

Chapter 6 : quantum mechanics - Compatible Observables - Physics Stack Exchange

It has to do with that theory of quantum mechanics and that electrons don't follow classical mechanics. Electrons remain in an unknown orbital path around a nucleus which doesn't follow the laws of classical electromagnetism. They are unpridictable. The problem with general relativity is that.

Dilaton The dilaton made its first appearance in Kaluzaâ€"Klein theory , a five-dimensional theory that combined gravitation and electromagnetism. It appears in string theory. The impetus arose from the fact that complete analytical solutions for the metric of a covariant N-body system have proven elusive in general relativity. This outcome revealed a previously unknown and already existing natural link between general relativity and quantum mechanics. The field equations are amenable to such a generalization, as shown with the inclusion of a one-graviton process, [23] and yield the correct Newtonian limit in d dimensions, but only with a dilaton. Furthermore, some speculate on the view of the apparent resemblance between the dilaton and the Higgs boson. Finally, since this theory can combine gravitational, electromagnetic, and quantum effects, their coupling could potentially lead to a means of testing the theory through cosmology and experimentation. Nonrenormalizability of gravity[edit] Further information: Renormalization General relativity, like electromagnetism , is a classical field theory. One might expect that, as with electromagnetism, the gravitational force should also have a corresponding quantum field theory. However, gravity is perturbatively nonrenormalizable. The theory must be characterized by a choice of finitely many parameters, which could, in principle, be set by experiment. For example, in quantum electrodynamics these parameters are the charge and mass of the electron, as measured at a particular energy scale. On the other hand, in quantizing gravity there are, in perturbation theory, infinitely many independent parameters counterterm coefficients needed to define the theory. For a given choice of those parameters, one could make sense of the theory, but since it is impossible to conduct infinite experiments to fix the values of every parameter, it has been argued that one does not, in perturbation theory, have a meaningful physical theory. At low energies, the logic of the renormalization group tells us that, despite the unknown choices of these infinitely many parameters, quantum gravity will reduce to the usual Einstein theory of general relativity. On the other hand, if we could probe very high energies where quantum effects take over, then every one of the infinitely many unknown parameters would begin to matter, and we could make no predictions at all. It is conceivable that, in the correct theory of quantum gravity, the infinitely many unknown parameters will reduce to a finite number that can then be measured. One possibility is that normal perturbation theory is not a reliable guide to the renormalizability of the theory, and that there really is a UV fixed point for gravity. Since this is a question of non-perturbative quantum field theory, it is difficult to find a reliable answer, but some people still pursue this option. Another possibility is that there are new, undiscovered symmetry principles that constrain the parameters and reduce them to a finite set. This is the route taken by string theory , where all of the excitations of the string essentially manifest themselves as new symmetries. Effective field theory In an effective field theory , all but the first few of the infinite set of parameters in a nonrenormalizable theory are suppressed by huge energy scales and hence can be neglected when computing low-energy effects. Thus, at least in the low-energy regime, the model is a predictive quantum field theory. An example is the well-known calculation of the tiny first-order quantum-mechanical correction to the classical Newtonian gravitational potential between two masses. Background independence A fundamental lesson of general relativity is that there is no fixed spacetime background, as found in Newtonian mechanics and special relativity ; the spacetime geometry is dynamic. While easy to grasp in principle, this is the hardest idea to understand about general relativity, and its consequences are profound and not fully explored, even at the classical level. To a certain extent, general relativity can be seen to be a relational theory , [29] in which the only physically relevant information is the relationship between different events in space-time. On the other hand, quantum mechanics has depended since its inception on a fixed background non-dynamic structure. In the case of quantum mechanics, it is time that is given and not dynamic, just as in Newtonian classical mechanics. In relativistic quantum field theory, just as in classical field theory, Minkowski spacetime is the fixed background of the theory. String theory[edit

] Interaction in the subatomic world: Although string theory had its origins in the study of quark confinement and not of quantum gravity, it was soon discovered that the string spectrum contains the graviton , and that "condensation" of certain vibration modes of strings is equivalent to a modification of the original background. Background independent theories[edit] Loop quantum gravity is the fruit of an effort to formulate a background-independent quantum theory. Topological quantum field theory provided an example of background-independent quantum theory, but with no local degrees of freedom, and only finitely many degrees of freedom globally. Semi-classical quantum gravity[edit] Quantum field theory on curved non-Minkowskian backgrounds, while not a full quantum theory of gravity, has shown many promising early results. In an analogous way to the development of quantum electrodynamics in the early part of the 20th century when physicists considered quantum mechanics in classical electromagnetic fields , the consideration of quantum field theory on a curved background has led to predictions such as black hole radiation. Phenomena such as the Unruh effect , in which particles exist in certain accelerating frames but not in stationary ones, do not pose any difficulty when considered on a curved background the Unruh effect occurs even in flat Minkowskian backgrounds. The vacuum state is the state with the least energy and may or may not contain particles. See Quantum field theory in curved spacetime for a more complete discussion. Problem of Time[edit] Main article: Problem of Time A conceptual difficulty in combining quantum mechanics with general relativity arises from the contrasting role of time within these two frameworks. In quantum theories time acts as an independent background through which states evolve, with the Hamiltonian operator acting as the generator of infinitesimal translations of quantum states through time. Candidate theories[edit] There are a number of proposed quantum gravity theories. They also face the common problem that, as yet, there is no way to put quantum gravity predictions to experimental tests, although there is hope for this to change as future data from cosmological observations and particle physics experiments becomes available. String theory Projection of a Calabiâ€"Yau manifold , one of the ways of compactifying the extra dimensions posited by string theory One suggested starting point is ordinary quantum field theories which are successful in describing the other three basic fundamental forces in the context of the standard model of elementary particle physics. However, while this leads to an acceptable effective quantum field theory of gravity at low energies, [27] gravity turns out to be much more problematic at higher energies. For ordinary field theories such as quantum electrodynamics , a technique known as renormalization is an integral part of deriving predictions which take into account higher-energy contributions, [35] but gravity turns out to be nonrenormalizable: In this way, string theory promises to be a unified description of all particles and interactions. Sorting through this large family of solutions remains a major challenge. Loop quantum gravity[edit] Main article: Its second idea is that the quantum discreteness that determines the particle-like behavior of other field theories for instance, the photons of the electromagnetic field also affects the structure of space. The main result of loop quantum gravity is the derivation of a granular structure of space at the Planck length. This is derived from following considerations: In the case of electromagnetism, the quantum operator representing the energy of each frequency of the field has a discrete spectrum. Thus the energy of each frequency is quantized, and the quanta are the photons. In the case of gravity, the operators representing the area and the volume of each surface or space region likewise have discrete spectrum. Thus area and volume of any portion of space are also quantized, where the quanta are elementary quanta of space. It follows, then, that spacetime has an elementary quantum granular structure at the Planck scale, which cuts off the ultraviolet infinities of quantum field theory. The quantum state of spacetime is described in the theory by means of a mathematical structure called spin networks. Spin networks were initially introduced by Roger Penrose in abstract form, and later shown by Carlo Rovelli and Lee Smolin to derive naturally from a non-perturbative quantization of general relativity. Spin networks do not represent quantum states of a field in spacetime: The theory is based on the reformulation of general relativity known as Ashtekar variables , which represent geometric gravity using mathematical analogues of electric and magnetic fields. One version starts with the canonical quantization of general relativity. These represent histories of spin networks. Other approaches[edit] There are a number of other approaches to quantum gravity. The approaches differ depending on which features of general relativity and quantum theory are accepted unchanged, and which features are modified.

Chapter 7 : Observable - Wikipedia

The aim of this work is to review the concepts of time in quantum field theory and general relativity to show their incompatibility. We prove that the absolute character of Newtonian time is present in quantum mechanics and also partially in quantum field theories which consider the Minkowski metric as the background spacetime.

Historical basis of quantum theory Basic considerations At a fundamental level, both radiation and matter have characteristics of particles and waves. The gradual recognition by scientists that radiation has particle-like properties and that matter has wavelike properties provided the impetus for the development of quantum mechanics. Influenced by Newton, most physicists of the 18th century believed that light consisted of particles, which they called corpuscles. From about , evidence began to accumulate for a wave theory of light. At about this time Thomas Young showed that, if monochromatic light passes through a pair of slits, the two emerging beams interfere, so that a fringe pattern of alternately bright and dark bands appears on a screen. The bands are readily explained by a wave theory of light. According to the theory, a bright band is produced when the crests and troughs of the waves from the two slits arrive together at the screen; a dark band is produced when the crest of one wave arrives at the same time as the trough of the other, and the effects of the two light beams cancel. Beginning in , a series of experiments by Augustin-Jean Fresnel of France and others showed that, when a parallel beam of light passes through a single slit, the emerging beam is no longer parallel but starts to diverge; this phenomenon is known as diffraction. Given the wavelength of the light and the geometry of the apparatus i. However, though the ideas of classical physics explain interference and diffraction phenomena relating to the propagation of light, they do not account for the absorption and emission of light. All bodies radiate electromagnetic energy as heat; in fact, a body emits radiation at all wavelengths. The energy radiated at different wavelengths is a maximum at a wavelength that depends on the temperature of the body; the hotter the body, the shorter the wavelength for maximum radiation. Attempts to calculate the energy distribution for the radiation from a blackbody using classical ideas were unsuccessful. A blackbody is a hypothetical ideal body or surface that absorbs and reemits all radiant energy falling on it. One formula, proposed by Wilhelm Wien of Germany, did not agree with observations at long wavelengths, and another, proposed by Lord Rayleigh John William Strutt of England, disagreed with those at short wavelengths. In the German theoretical physicist Max Planck made a bold suggestion. He assumed that the radiation energy is emitted, not continuously, but rather in discrete packets called quanta. Planck showed that the calculated energy spectrum then agreed with observation over the entire wavelength range. Furthermore, emission takes place as soon as the light shines on the surface; there is no detectable delay. Einstein showed that these results can be explained by two assumptions: The spectra of light emitted by gaseous atoms had been studied extensively since the midth century. It was found that radiation from gaseous atoms at low pressure consists of a set of discrete wavelengths. This is quite unlike the radiation from a solid, which is distributed over a continuous range of wavelengths. The set of discrete wavelengths from gaseous atoms is known as a line spectrum , because the radiation light emitted consists of a series of sharp lines. The wavelengths of the lines are characteristic of the element and may form extremely complex patterns. The simplest spectra are those of atomic hydrogen and the alkali atoms e. For a given value of m, the lines for varying n form a series. The model was based on the experiments of Hans Geiger and Ernest Marsden , who in bombarded gold atoms with massive, fast-moving alpha particles; when some of these particles were deflected backward, Rutherford concluded that the atom has a massive, charged nucleus. Bohr made three assumptions. First, he postulated that, in contrast to classical mechanics, where an infinite number of orbits is possible, an electron can be in only one of a discrete set of orbits, which he termed stationary states. The force on the electron the analogue of the gravitational force between the Sun and a planet is the electrostatic attraction between the positively charged nucleus and the negatively charged electron. Its two most important features have survived in present-day quantum mechanics. They are 1 the existence of stationary, nonradiating states and 2 the relationship of radiation frequency to the energy difference between the initial and final states in a transition. Scattering of X-rays Soon scientists were faced with the fact that another form of radiation, X-rays, also exhibits both wave and particle properties. Max von Laue of Germany had shown in that crystals can be used as three-dimensional diffraction gratings for X-rays; his technique constituted the fundamental evidence for the wavelike nature of X-rays. The atoms of a crystal, which are arranged in a regular lattice, scatter the X-rays. For certain directions of scattering, all the crests of the X-rays coincide. The scattered X-rays are said to be in phase and to give constructive interference. For these directions, the scattered X-ray beam is very intense. Clearly, this phenomenon demonstrates wave behaviour. In fact, given the interatomic distances in the crystal and the directions of constructive interference, the wavelength of the waves can be calculated. In the American physicist Arthur Holly Compton showed that X-rays scatter from electrons as if they are particles. Compton performed a series of experiments on the scattering of monochromatic, high-energy X-rays by graphite. To interpret his results, Compton regarded the X-ray photon as a particle that collides and bounces off an electron in the graphite target as though the photon and the electron were a pair of dissimilar billiard balls. Application of the laws of conservation of energy and momentum to the collision leads to a specific relation between the amount of energy transferred to the electron and the angle of scattering. De Broglie proposed that matter has wave as well as particle properties. Using a crystal of nickel, they diffracted a beam of monoenergetic electrons and showed that the wavelength of the waves is related to the momentum of the electrons by the de Broglie equation. All behave like waves with the same wavelength-momentum relationship. Attempts were made to apply the theory to more complicated systems than the hydrogen atom. However, the ad hoc mixture of classical and quantum ideas made the theory and calculations increasingly unsatisfactory. Then, in the 12 months started in July , a period of creativity without parallel in the history of physics, there appeared a series of papers by German scientists that set the subject on a firm conceptual foundation. The papers took two approaches: The protagonists were not always polite to each other. He was guided by a mathematical formulation of optics , in which the straight-line propagation of light rays can be derived from wave motion when the wavelength is small compared to the dimensions of the apparatus employed. Thus, It is assumed that the particle is boundâ€”i. Since the potential varies with position, two other quantities do also: The required quantum results follow from certain reasonable restrictions placed on the wave functionâ€”for example, that it should not become infinitely large at large distances from the centre of the potential. The nucleus a proton of charge e is situated at the origin, and r is the distance from the origin to the position of the electron. These functions are characterized by a trio of integers n, l, m, termed quantum numbers. The values of E depend only on the integers n 1, 2, 3, etc. The distinction between the two interpretations is important. Thus, the concept of the electron as a point particle moving in a well-defined path around the nucleus is replaced in wave mechanics by clouds that describe the probable locations of electrons in different states. Electron spin and antiparticles In the English physicist Paul A. Dirac produced a wave equation for the electron that combined relativity with quantum mechanics. Dirac showed that an electron has an additional quantum number ms. It corresponds to an additional form of angular momentum ascribed to a spinning motion. The angular momentum mentioned above is due to the orbital motion of the electron, not its spin. The concept of spin angular momentum was introduced in by Samuel A. Goudsmit and George E. Uhlenbeck , two graduate students at the University of Leiden, Neth. The magnetic moment of a particle is closely related to its angular momentum; if the angular momentum is zero, so is the magnetic moment. Yet Stern and Gerlach had observed a magnetic moment for electrons in silver atoms, which were known to have zero orbital angular momentum. Goudsmit and Uhlenbeck proposed that the observed magnetic moment was attributable to spin angular momentum. The electron-spin hypothesis not only provided an explanation for the observed magnetic moment but also accounted for many other effects in atomic spectroscopy, including changes in spectral lines in the presence of a magnetic field Zeeman effect , doublet lines in alkali spectra, and fine structure close doublets and triplets in the hydrogen spectrum. The Dirac equation also predicted additional states of the electron that had not yet been observed. Experimental confirmation was provided in by the discovery of the positron by the American physicist Carl David Anderson. Every particle described by the Dirac equation has to have a corresponding antiparticle , which differs only in charge. The positron is just such an antiparticle of the negatively charged electron, having the same mass as the latter but a positive charge. Identical particles and multielectron atoms Because electrons are identical to i. The problem of identical particles does not arise in classical physics, where the objects are large-scale and can always be distinguished, at least in principle. There is no way, however, to differentiate two electrons in the same atom, and the form of the wave function must reflect this fact. The symmetry of the wave function for identical particles is closely related to the spin of the particles. They are called fermions after the Italian-born physicist Enrico Fermi. Particles with zero or integral spin e. The requirement of antisymmetric wave functions for fermions leads to a fundamental result, known as the exclusion principle , first proposed in by the Austrian physicist Wolfgang Pauli. The exclusion principle states that two fermions in the same system cannot be in the same quantum state. If they were, interchanging the two sets of coordinates would not change the wave function at all, which contradicts the result that the wave function must change sign. Thus, two electrons in the same atom cannot have an identical set of values for the four quantum numbers n, l, m, ms. The exclusion principle forms the basis of many properties of matter, including the periodic classification of the elements, the nature of chemical bonds, and the behaviour of electrons in solids; the last determines in turn whether a solid is a metal, an insulator, or a semiconductor see atom ; matter. The principles of the calculation are well understood, but the problems are complicated by the number of particles and the variety of forces involved. The forces include the electrostatic forces between the nucleus and the electrons and between the electrons themselves, as well as weaker magnetic forces arising from the spin and orbital motions of the electrons. Despite these difficulties, approximation methods introduced by the English physicist Douglas R. Hartree , the Russian physicist Vladimir Fock , and others in the s and s have achieved considerable success. Such schemes start by assuming that each electron moves independently in an average electric field because of the nucleus and the other electrons; i. Each electron has its own wave function, called an orbital. The overall wave function for all the electrons in the atom satisfies the exclusion principle. Corrections to the calculated energies are then made, which depend on the strengths of the electron-electron correlations and the magnetic forces. For example, an atom may change spontaneously from one state to another state with less energy, emitting the difference in energy as a photon with a frequency given by the Bohr relation. If electromagnetic radiation is applied to a set of atoms and if the frequency of the radiation matches the energy difference between two stationary states, transitions can be stimulated.

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Chapter 8 : Why general relativity and quantum mechanics are incompatible? | Physics Forums

The Final Contradiction The results described above constitute quite an achievement for one century, but it leaves us with one fundamental contradiction that still needs to be resolved. General relativity and quantum field theory are incompatible.

Why does relativity require space to be continuous? Why is it necessary to distinguish between the right and left point? Where is the boarder between distinguishing 2 atoms and fusing them together? Or are the 2 points only meant for theoretical points that are infinatly small? Are there other problems between QM and relativity? That show some photons that have come from a pulsar â€¦these photons have been measured to show that there may be a quantised state of spaceâ€¦because some of the photons are a tiny fraction slower due to interaction of small peices of clumpy spaceâ€¦ Stephen Tuck August 22, at Since all matter and space is composed of photons, the discrete quanta makeup the smallest packets of energy. The Planck Units are the minimums and maximums of energy. Planck Mass is when all frequency-energy the Time-component has converted into wavelength the Space-component; photonic-string length. Photons are not massless, which is why they impart momentum when they strike the surface of an object. Space does not have discontinualities because it behaves as Discrete, Multivariate Linear Equations. Differential Equations are incomplete approximations because if they had all the variables, they would be Multivariate Calculus Equations. The c-constant is an energy-constant like a base unit since the speed-of-light depends upon the Parameters-of-Space. That is why Gravitational Lensing could most accurately be described as Gravitational Refraction. The Physics behind light slowing-down as it travels through a glass of water is the same behind the bending of light around a massive object such as the sun. You are probably looking for terms like Abelian and non-Abelian, but such formalisms are of no practical importance in the TOE since Space is commutative and Euclidian in nature. Also, throw out imaginary numbers because they are the product of light-cone mapping, which is due to the incorrect treatment of Time as a spatial coordinate rather than as kinetic energy. If you study my work on ToeQuest, you will find that the predominate mathematical framework of physics is incorrect Lorentz-Invariance, Guage-Invariance. The preferred frame of reference is the Aether Rest-Frame because if you measure the universe from a frame-of-motion, the speed-of-light would appear superluminal due to Time-Dilation meaning that it is Lorentz-variant. That is why the Gravitational-Constant has seasonal variation due to mass-increase and time-dilation of the Lorentz transformation since the earth is moving at a different speed along its elliptical-orbit. Of course, if the photonic-string manifold of a particle changes size due to photonic-string lengthening; mass-increase , it means that matter is not Guage-Invarient because physically-meaningful quantities like mass and fiber-bundle size do change. The Higgs Mechanism is an incorrect theoretical construct because Spontaneous Symmetry Breaking explains nothing. The Higgs Mechanism is actually the Lorentz Mechanism, which is the action of the Lorentz transformations. We draw lines in the sand, but Quantum Mechanics is just Vector Calculus where Tensors are useful tools for group operations. The subatomic particles simultaneously interact at the Quantum Level forming stable orbits as kinetic-energy bonds. Things like the Lorentz Force take part in this orbital-stabilization between atoms in the Electron Perihelion Spheres of molecular formation. Stephen Tuck August 23, at 8: I have given some further thought to Space being Eiclidean. With Euclidean Geometry, you have to admit certain exceptions because physical objects are not completely rigid since they expand or contract. Thermodynamics itself is adding or removing energy in the form of heat infrared photons , that changes the physical properties of matter or physically-meaningful properties in terms of Guage-Invariance. It causes phase-change and the increase or decrease in the mass of an object as well as affecting its kinetic energy. Interestingly, this naturally leads to the Lorentz transformations. However, it is a stationary form of increased kinetic energy in which heating generally leads to an expansion decrease in density and cooling leads to a contraction increase in density. Instead of the normal effect of Time-Dilation of an object-in-motion, there is a increase in the rate of Time from heating because the frequency kinetic-energy Time-component increases rather than decreases. That is why heat increases the rate of chemical reactions. A transformation of Space Rotational Motion into Matter bound Linear Motion should be possible just as matter falling into a black hole converts into Space, causing the accelerated expansion of the universe. I would rather refer to the geometry of the universe as Lorentzian after the Lorentz transformations rather than Euclidean. It seems that the universe has Lorentzian Space rather than Euclidean Space. At the center of every galaxy lies a black hole, which is a point of universal expansion. It looks like I will have to look into Differential Equations as a means of the functional variation of the rate of expansion of Space using deterministic Multivariate Calculus for a rate-varying, differential coordinate system rather than for approximating the missing variables of Multivariate Calculus Equations as it is most often incorrectly applied! Stephen Tuck August 23, at 1: Previously, I had thought that it would take different varients of the equation rather than an integrated approach, but all varient forms should work together as seemless extensions of Quantum Mechanics. The trick is that the mechanics of a photon does not merely vanish when it wraps-up into a particle manifold. The thing is that the string Tension or Rigidity will correlate to the vibrational frequency and wavelength. Imagine a guitar string where the diameter of the string and the tension on the string produce a specific audio frequency pitch based upon the amount of vibration applied by the guitarist affecting the amplitude or loudness of the waves.

Chapter 9 : Incompatibility between Quantum Mechanics and Relativity | Physics Forums

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Rex Features Craig Hogan, a theoretical astrophysicist at the University of Chicago and the director of the Center for Particle Astrophysics at Fermilab, is reinterpreting the quantum side with a novel theory in which the quantum units of space itself might be large enough to be studied directly. To understand what is at stake, look back at the precedents. It provided the conceptual tools for the Large Hadron Collider , solar cells, all of modern microelectronics. What emerges from the dust-up could be nothing less than a third revolution in modern physics, with staggering implications. It could tell us where the laws of nature came from, and whether the cosmos is built on uncertainty or whether it is fundamentally deterministic, with every event linked definitively to a cause. Small is beautiful Hogan, champion of the quantum view, is what you might call a lamp-post physicist: The clash between relativity and quantum mechanics happens when you try to analyse what gravity is doing over extremely short distances, he notes, so he has decided to get a really good look at what is happening right there. But Hogan questions whether that is really true. Just as a pixel is the smallest unit of an image on your screen and a photon is the smallest unit of light, he argues, so there might be an unbreakable smallest unit of distance: There would be no way for gravity to function at the smallest scales because no such scale would exist. Or put another way, general relativity would be forced to make peace with quantum physics, because the space in which physicists measure the effects of relativity would itself be divided into unbreakable quantum units. The theatre of reality in which gravity acts would take place on a quantum stage. Hogan acknowledges that his concept sounds a bit odd, even to a lot of his colleagues on the quantum side of things. Since the late s, a group of physicists and mathematicians have been developing a framework called string theory to help reconcile general relativity with quantum mechanics; over the years, it has evolved into the default mainstream theory, even as it has failed to deliver on much of its early promise. Like the chunky-space solution, string theory assumes a fundamental structure to space, but from there the two diverge. String theory posits that every object in the universe consists of vibrating strings of energy. Like chunky space, string theory averts gravitational catastrophe by introducing a finite, smallest scale to the universe, although the unit strings are drastically smaller even than the spatial structures Hogan is trying to find. Chunky space does not neatly align with the ideas in string theory â€” or in any other proposed physics model, for that matter. It would suggest new ways to understand the inherent nature of space and time. And weirdest of all, perhaps, it would bolster the notion that our seemingly three-dimensional reality is composed of more basic, two-dimensional units. What makes them drastically different is that he plans to put them to a hard experimental test. As in, right now. A living thing in two places at once? This quantum quandary test is limited Read more Starting in , Hogan began thinking about how to build a device that could measure the exceedingly fine graininess of space. As it turns out, his colleagues had plenty of ideas about how to do that, drawing on technology developed to search for gravitational waves. The name is an esoteric pun, referencing both a 17th-century surveying instrument and the theory that 2D space could appear three-dimensional, analogous to a hologram. Beneath its layers of conceptual complexity, the holometer is technologically little more than a laser beam, a half-reflective mirror to split the laser into two perpendicular beams, and two other mirrors to bounce those beams back along a pair of 40m-long tunnels. The beams are calibrated to register the precise locations of the mirrors. If space is chunky, the locations of the mirrors would constantly wander about strictly speaking, space itself is doing the wandering , creating a constant, random variation in their separation. For the scale of chunkiness that Hogan hopes to find, he needs to measure distances to an accuracy of m, about m times smaller than a hydrogen atom, and collect data at a rate of about m readings per second. Amazingly, such an experiment is not only possible, but practical. Hogan has his share of fierce sceptics, including many within the theoretical physics community. The reason for the disagreement is easy to appreciate: Despite this superficial sparring, though, Hogan and most of his theorist colleagues share a deep core conviction: The other three laws of physics follow quantum rules, so it makes sense that gravity must as well. Chunky space certainly aligns with that worldview. Hogan likens his project to the landmark Michelson-Morley experiment of the 19th century, which searched for the aether â€” the hypothetical substance of space that, according to the leading theory of the time, transmitted light waves through a vacuum. It will show the right way or rule out the wrong way to understand the underlying quantum structure of space and how that affects the relativistic laws of gravity flowing through it. A bigger vision If you are looking for a totally different direction, Smolin of the Perimeter Institute is your man. Where Hogan goes gently against the grain, Smolin is a full-on dissenter: Smolin thinks the small-scale approach to physics is inherently incomplete. Current versions of quantum field theory do a fine job explaining how individual particles or small systems of particles behave, but they fail to take into account what is needed to have a sensible theory of the cosmos as a whole. A more fruitful path forward, he suggests, is to consider the universe as a single enormous system, and to build a new kind of theory that can apply to the whole thing. And we already have a theory that provides a framework for that approach: Instead, all of reality is described in terms of relationships between objects and between different regions of space. Even something as basic as inertia the resistance of your car to move until forced to by the engine, and its tendency to keep moving after you take your foot off the accelerator can be thought of as connected to the gravitational field of every other particle in the universe.